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The first meeting of the Society occurred December 20, 1870. The organization then effected continued until February 21, 1872, when the second meeting was held. Since that time there has been a meeting each year, as shown below. The respective presidents were elected at the meeting, at the place, and for a period shown opposite thier names, but they presided at the subsequent meeting.

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3.	William Clift	1873–1874	New York, N. Y.
4.	Robert B. Roosevelt	1874–1875	New York, N. Y.
5.	Robert B. Roosevelt	1875–1876	New York, N. Y.
6.	Robert B. Roosevelt	1876–1877[1]	New York, N. Y.
7.	Robert B. Roosevelt	1877–1878	New York, N. Y.
8.	Robert B. Roosevelt	1878–1879	New York, N. Y.
9.	Robert B. Roosevelt	1879–1880	New York, N. Y.
10.	Robert B. Roosevelt	1880–1881	New York, N. Y.
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42.	Charles H. Townsend	1912–1913	Denver, Colo.

[1] A special meeting was held at the Centennial Grounds, Philadelphia, Pa., October 6 and 7, 1876.

43.	Henry B. Ward	1913–1914	Boston, Mass.
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63.	Fred A. Westerman	1933–1934	Columbus, Ohio
64.	E. L. Wickliff	1934–1935	Montreal, P. Q.
65.	Frank T. Bell	1935–1936	Tulsa, Okla.
66.	A. G. Huntsman	1936–1937	Grand Rapids, Mich.
67.	I. T. Quinn	1937–1938	Mexico City, Mexico
68.	Fred J. Foster	1938–1939	Asheville, N. C.
69.	T. H. Langlois	1939–1940	San Francisco, Calif.
70.	James Brown	1940–1941	Toronto, Ont.
71.	John Van Oosten	1941–1942	St. Louis, Mo.
72.	John Van Oosten	1942–1943	(No meeting)[2]
73.	John Van Oosten	1943–1944	(No meeting)[3]
74.	John Van Oosten	1944–1945	(No meeting)[3]
75.	John Van Oosten	1945–1946	(No meeting)[3]
76.	Joseph R. Hogan	1946–1947	St. Paul, Minn.
77.	H. H. MacKay	1947–1948	Denver, Colo.
78.	Seth Gordon	1948–1949	Atlantic City, N. J.
79.	Milton C. James	1949–1950	Winnipeg, Man.
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81.	W. J. K. Harkness	1951–1952	Rochester, N. Y.
82.	Ralph Hile	1952–1953	Dallas, Texas
83.	Fred A. Thompson	1953–1954	Milwaukee, Wis.
84.	A. L. Pritchard	1954–1955	Seattle, Wash.
85.	George A Sprecher	1955–1956	Augusta, Ga.
86.	Clarence F. Pautzke	1956–1957	Toronto, Ont.

[2] The annual meeting scheduled to be held in New Orleans, La., was cancelled because of the war emergency.

[3] No annual meeting scheduled because of the war.

In Memoriam

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Part 1
Papers

THE LIFE HISTORY AND ECOLOGY OF THE YELLOW WALLEYE, *STIZOSTEDION VITREUM*, IN LAC LA RONGE, SASKATCHEWAN

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Department of Biology,
University of Saskatchewan

Abstract

The yellow walleye population of Lac la Ronge was studied from 1950 to 1956 using creel census, tagging, trapping the spawning run and extensive gill netting.

Spawning runs of thirteen to thirty thousand walleyes enter the Montreal and Potato Rivers a few days after the ice leaves the rivers and small lakes but much earlier than the break-up of ice on Lac la Ronge. Maximum spawning activity was in water temperatures of 45-50°F. Males outnumber females in the run by 5 to 1. A few spawned at 5 years but the bulk of the run was 8 to 10 years old.

The rate of growth of walleyes in Lac la Ronge is intermediate as compared to that recorded elsewhere in Canada and in the United States. Females grow considerably faster than males. The food was 97 percent fish with ciscoes and ninespine sticklebacks as the main items. External and internal parasites are reported.

Movements of the walleye population were followed through the spawning run, gradual return to the main lake and late summer dispersal into deep water. Greater activity was demonstrated at night than during the day. Seventy percent of the recoveries were within two miles of the tagging site and only 5 percent more than 20 miles away. One walleye had gone 65 miles upstream. Tagging and other evidence suggests that the spawning runs of two rivers about 6 miles apart represent essentially discrete populations.

The angler's catch of walleyes, averaging 41,000 pounds per year, is of the same order as the previous commercial catch. Six years of creel census indicates that the walleyes have contributed steadily, about 17 percent of the game fish catch. The population appears quite capable of supporting present rates of utilization.

Introduction

The yellow walleye, locally called pickerel, is one of three game species which support a very large angling fishery in Lac la Ronge, a lake of 550 square miles in the Churchill River valley of northern Saskatchewan. Although exceeded in the annual catch by pike and lake trout, the walleye is much desired and provides roughly one-third of the angling catch during the first half of the fishing season. Moderate quantities of walleyes are taken unavoidably in the commercial operations which, on Lac la Ronge, are intended to harvest the whitefish population. Thus in order to conserve the walleyes for angling and to manage the commerical operation, it was necessary to obtain detailed information as to the life history, growth, population and movements of this species.

Walleye populations in more southern waters have been the subject of intensive studies by Carlander (1945), Eschmeyer (1950), Smith *et al.*

(1952), Hile (1954) and others. Thus one purpose of the present study was to determine the extent to which the findings of these earlier investigations applied to the walleyes of this lake in the northern part of their range. The situation at Lac la Ronge was especially favourable for studies of the spawning runs, growth and population movements.

Observations on the growth and ecology of the walleyes began in 1948 as a part of the biological survey of Lac la Ronge which continued for three years and was reported by Rawson and Atton (1953). In 1950 a detailed creel census was initiated and in 1951 tagging of walleyes was begun. In the summers of 1954 and 1955 a full-time investigation continued and expanded the study with particular emphasis on the spawning run and gill netting to determine habits and movements of walleyes in the lake.

Spawning

The walleyes of Lac la Ronge run into numerous tributary streams for spawning. Lake spawning has not been observed in la Ronge although common in Potato Lake. Two of the larger Spawning streams near La Ronge have been used by the Fisheries Branch for spawn-taking and this has made possible a careful study of their annual runs. The first is the Montreal River, the largest inlet to the lake, which drains through Egg and Bigstone Lakes to enter Lac la Ronge at the west end of the townsite (Figure 1). The second is the Potato River which drains Potato Lake and enters Lac la Ronge about 6 miles south of the townsite. Impounding traps were set to catch the upstream migration in the Montreal River in the years 1951, 1952 and 1954, although in 1954 flooding made it impossible to operate the trap for the whole run. In 1953 a trap was operated in Potato Lake about 100 yards offshore and near the mouth of a small creek. In 1954 the run was trapped in Highway Creek about one mile above Potato Lake. In 1955 floods at this site made it necessary to move the trap again to the 1953 site in Potato Lake, but in 1956 it was again operated in Highway Creek. The following observations on spawning runs were drawn from the six years of operations in these two streams.

Numerical strength of spawning runs over a six-year period is indicated in Table 1. In 1951 and 1952 the traps were operated in the Montreal River through the whole of the run. In the remaining years high water or lack of personnel made it necessary to remove the trap after the main run had passed and sufficient eggs, usually 50 to 75 million, had been taken. The numbers recorded for these years include those counted plus an estimate of the number running after removal of the trap. The actual count of walleyes in 1953 was 14,300, in 1954 17,700, in 1955 18,500 and in 1956 16,680. The traps in Highway Creek and Potato Lake caught only a part of the run which left Lac la Ronge through the Potato River. It is believed that this total run would average close to 40,000 as com-

TABLE 1.—*Summary of information on walleye spawning runs in two rivers at Lac la Ronge, 1951 to 1956.*

	1951	1952	1953	1954	1955	1956
Location of trap	Montreal R.	Montreal R.	Potato L.	Highway Cr.	Potato L.	Highway Cr.
Estimated number in total run	19,000	13,000	20,000	30,000	18,000	25,000
Duration of run	April 8-May 11	April 17-May 8	May 2-13	May 4-25	April 30-May 15	May 6-22
Main spawning period	April 30-May 5	May 1-7	May 5-9	May 17-21	May 7-12	May 12-18
Range of water temperature during spawning, °F	45°-49°	46°-52°	42°-50°	38°-45°	39°-44°	40°-42°
Break-up of ice on Lac la Ronge	June 1	May 16	May 21	June 7	May 25	May 28
Break-up of ice on Potato Lake	—	—	May 4	May 15	May 3	May 13
Comments	Water warm, run to sharp maximum of 3000 fish per day on May 2.	Run early but slow. No maximum. Never more than 1000 per day.	Run concentrated. Maximum of 4000 May 6.	Slow run and latest spawning date on record.	Run concentrated. 5000 on May 8, then diminished.	Maximum 4700 on May 12 and sustained several days.

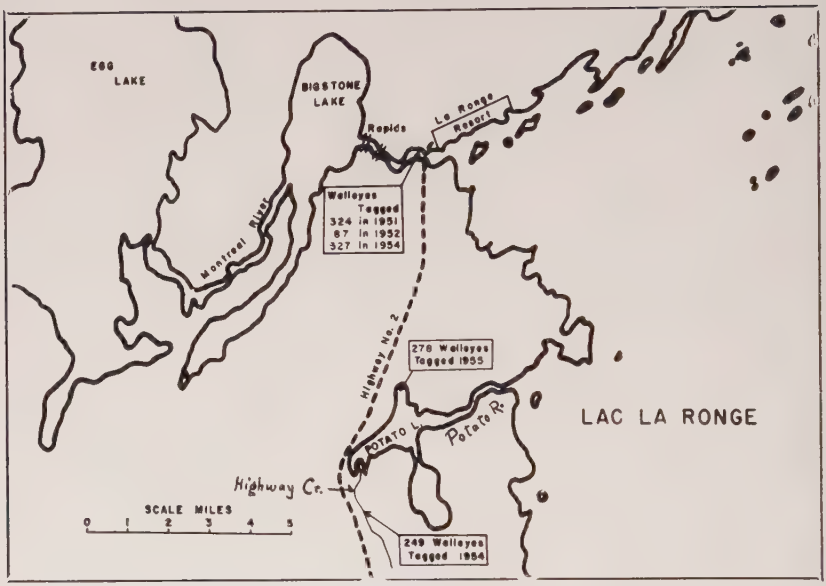

FIGURE 1. Map of a part of Lac la Ronge showing the location of two streams in which the spawning runs were studied.

pared to the average of 16,000 in the two-year count at the Montreal River.

The time of spawning varied in different years, from the end of April to the end of the third week in May and the movement of the spawning run extended over a wider period. In 1952 a trap was placed in the Montreal River on April 14 and on April 17 considerable numbers of walleyes began to come upstream. In 1954 the run from Potato Lake up Highway Creek continued until May 25. This represents the extremes of spawning movement. In two years, 1952 and 1954, the run was slow and protracted, but in the remaining four years it built up rapidly to a maximum and was completed in a week to ten days. This concentration appeared to be brought on by higher water temperatures. The main spawning is indicated in Table 1 as occurring in period of 5 to 7 days usually between May 1 and 15, but in 1954 delayed to May 21.

Water temperatures appear to be the controlling influence for the spawning run. Little movement was observed in water temperatures below 38°F. (3.3°C.). The main run usually took place at 40 to 42°F. (4.4-5.6°C.) and some spawning occurred at these temperatures. More active spawning was usually observed between 45 and 50°F. (7.7-10°C.). In two seasons, when water temperatures remained at 51 and 52°F. (10.6-

11.1°C.) for a day or two, the females spawned in the traps or holding nets and large quantities (20-30 quarts) of eggs were recovered from the bottom of the nets. It should be noted that the diurnal variation in water temperature in these streams at spawning time is usually about 4°F. (2.2°C.) and that the temperatures quoted above are averages. Essentially similar relations of spawning activity to temperature were observed in Michigan by Eschmeyer (1950) with some spawning at 40-44°F. (4.4-6.7°C.) but preferred temperatures of 46 to 48°F. (7.8-8.9°C.).

The breakup of ice on Potato Lake was usually followed in one or two days by the walleye spawning run (see Table 1.) However, the runs from Lac la Ronge into the Potato and Montreal Rivers occurred long before the breakup of ice on Lac la Ronge and showed no relation to that event. Thus in 1951 the spawning run in the Montreal River occurred at the beginning of May while the ice remained on the main lake until June 1. Presumably the inflow of warmed water from the small lake stimulates the upstream movement of walleyes beneath the ice of the main lake.

The composition of the spawning run has been examined in some detail with reference to sex-ratio, size and age. A predominance of males was observed throughout the run. For the first four or five days, females were extremely scarce, often only 1 to 5 percent of the catch. In the main run our samples in several years averaged about 17 percent females and in no sample was the percentage above 30. Similar ratios were recorded by Eschmeyer (1950) in Lake Gogebic, while Eddy and Surber (1947) mention a 2:1 ratio of males to females in Lake Bemidji. It would seem that the males tend to arrive first in the spawning run and to remain longer than the females. This was Eschmeyer's conclusion from his observations on Lake Gogebic. Our own data do not rule out the additional possibility that some females do not spawn every year. In any case the lake population appears to include nearly equal numbers of males and females. Gill net sampling in the open water of Lac la Ronge during the summer of 1954 took 122 males and 120 females, in 1955, 127 males and 142 females.

The size distribution of walleyes in the spawning runs varied somewhat from year to year and between the Montreal River and Potato River systems. In general the individuals ranged from 14 to 26 inches fork length with averages usually between 17 and 21 inches. Since the sex ratio was unbalanced and varied during the run, it was necessary to consider males and females separately in determining the size distribution. Random sub-samples were measured throughout the run, but these were aggregated after determining that there were no extensive or consistent changes in length during the period of sampling. A characteristic length distribution of 490 male and 476 female walleyes from the Highway Creek run of 1956 is illustrated in the frequency diagram (Figure 2). These fish were measured to tenths of inches fork length but have been

placed in half-inch groups for plotting. Most of the males were from 15 to 24 inches and averaged 19.2 while the females were mainly from 18 to 26 inches averaging 21.7. The average lengths of males and females in five runs followed by the number of fish measured, in brackets, were as follows:

	Males, average length, inches	Females, average length, inches
1951 - Montreal River	17.4 (162)	19.1 (113)
1954 - Montreal River	17.2 (201)	18.3 (99)
1954 - Highway Creek	19.3 (236)	20.7 (17)
1955 - Potato Lake	18.5 (241)	20.0 (37)
1956 - Highway Creek	19.2 (490)	21.7 (476)

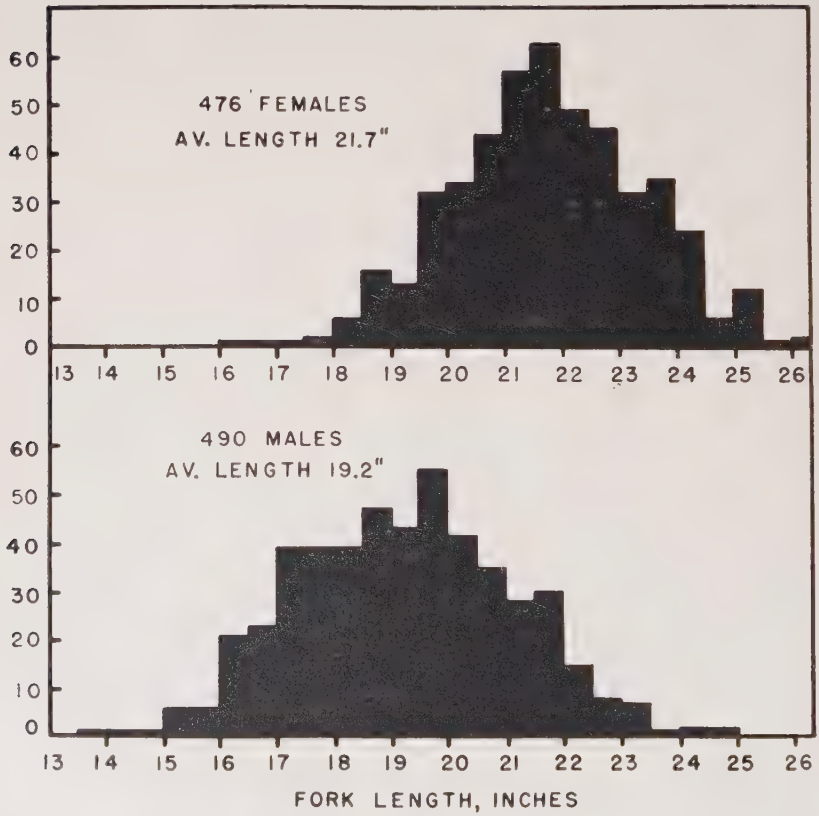

FIGURE 2. Length distribution of male and female walleyes in a representative sample from Highway Creek, near Potato Lake, Lac la Ronge, May 9 to 15, 1956.

Though the samples differ considerably in average length, the females were consistently longer than the males by amounts ranging from 7 to 13 percent. The walleyes in the Montreal River run were considerably smaller than those in Potato River, a fact noted also by hatchery operator, Mr. D. Snell, who obtained about 50 percent more eggs per female from the later run. This size difference is also of interest in the question of discreteness of the two populations, discussed below.

The dominant age groups in the spawning runs were 8 to 10 years. A very small percentage of the males enter the run at 5 years and about 13 inches fork length and a few females at 5 years and 14 inches. This agrees with the age at maturity as determined by examination of gonads of large numbers of walleyes caught in Lac la Ronge during several summers. Fifty percent of the males are mature at 7 years, and average length of 17 inches and fifty percent of the females at 7 years, and about 18 inches in length. The average length of the males in the run illustrated in Figure 2 is 19.2 inches, close to the average length for males of 9 years while the average length of females, 21.7 is greater than that for 10 years. Thus the males and females of the runs differ in age as well as in length. A considerable number of walleyes 11 and 12 years of age were taken but very few of 13 and older. The exact age of fish older than 13 years was difficult to determine.

Rate of Growth

The growth of young-of-the-year walleyes in Lac la Ronge is indicated in a general way by specimens taken in seine hauls during the several years of study. Combining the data from 14 collections, the average growth may be indicated as follows: June 30 - 0.9″ fork length, July 31 - 2.2″, August 31 - 3.5″, September 30 - 4.1″. Several specimens taken early in their second year (June) averaged 4.7″. Individual fish hatched in the same year grew at rather varied rates. Thus 14 specimens taken in one seine haul on August 28, 1954 ranged from 2.8 to 4.3 inches in length. The growth pattern indicated above for young walleyes in Lac la Ronge is much like that recorded by Raney and Lachner of Oneida Lake (1942). However, the spawning season in Lac la Ronge is about a month later and autumn growth slows down earlier. Thus although the growth curves are roughly parallel, the Oneida Lake walleyes reached an average total length of 133 mm., fork length about 4.9 inches, on October 24 as compared to 4.1 inches in Lac la Ronge at the end of September.

Growth in length has been determined from scales and measurements of walleyes taken from the lake with gill nets during the summer. The averages and range of lengths for each year class up to XIII are indicated in Table 2 and the average lengths, for both males and females, in the graph, (Figure 3). Since the samples were taken from June to September, esentially the whole growing season in this lake, the averages shown can be considered as indicating the mid-point in growth for any year class. Thus a close ap-

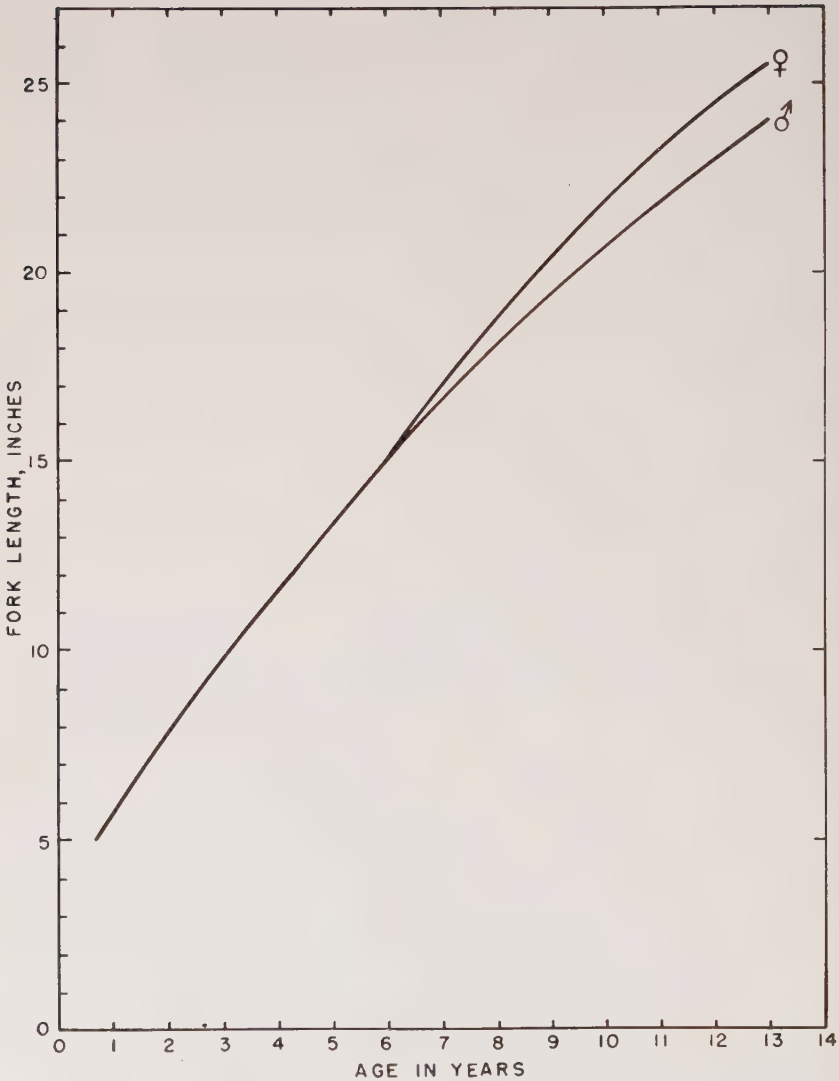

FIGURE 3.—Average fork lengths of male and female walleyes, ages one to thirteen years, in La la Ronge.

proximation of length at the end of any year can be obtained by adding one-half of the annual increment. Using this procedure, averaging growth for males and females and using the factor 1.05 to convert from fork to total length, the following average total lengths at the end of each year are obtained:

II — 9.2 inches	VIII — 20.0 inches
III — 11.1 inches	IX — 21.5 inches
IV — 12.9 inches	X — 22.9 inches
V — 14.9 inches	XI — 24.2 inches
VI — 16.7 inches	XII — 25.4 inches
VII — 18.4 inches	XIII — 26.6 inches

A striking feature of the growth, as shown in Figure 3, is the divergence between the sexes which begins to show at about 7 years. From this point the females grow faster until at 13 years they average 1.5 inches longer than the males. Differential growth in walleyes has been reported in Lake Gogebic by Eschmeyer (1950) and in Saginaw Bay by Hile (1954). In both cases the females were from 12 to 15 percent longer than the males at age X; total length 18-20 inches. At similar size and age the female walleyes of Lac la Ronge were about 6 per cent longer than the males, Table 2. It is of interest that Carlander (1945) found a still smaller difference, about 3 per cent, in walleyes about 15 inches long in Lake of the Woods and that Kennedy (1949) found that in Lake Manitoba "males and females grow at approximately the same rate."

Comparative data on the growth of walleyes in other lakes of Saskatchewan are available in unpublished reports by the writer, and by Mr. F. M. Atton and associates in the Fisheries Branch, Saskatchewan Department of Natural Resources. Growth in length of walleyes in Lac la Ronge is faster by about 12 percent than in Churchill, Big Peter Pond and Ile a la Crosse, lakes which lie higher up in the Churchill River Drainage. In Amisk and Reindeer lakes which are also in the Churchill drainage but in the northeast part of Saskatchewan, walleye growth is almost identical with that in Lac la Ronge. Considerably faster growth has been observed in the walleyes of Last Mountain, Echo and Pasqua lakes in the Qu' Appelle drainage of southeastern Saskatchewan.

Growth rates of walleyes in Canada and the United States have been compared by several authors. A useful summary is provided by Eschmeyer (1950, page 75) who compared growth in 16 waters, having recalculated the data of various authors to express it in total length in inches at the end of the year. The fastest growth rates were recorded from moderate sized lakes in Minnesota (Eddy & Carlander 1939), Iowa (Carlander 1948) and Wisconsin (Schloemer & Lorch 1942) and in the Norris Reservoir, Tennessee (Stroud 1949). Walleyes from these waters are often 25 to 30 percent longer than those of the same age from Lac la Ronge. Walleyes from Lake of the Woods (Carlander 1945) grew at a rate almost identical with that in Lac la Ronge while those in Lake Manitoba (Kennedy 1949),

TABLE 2.—*Average and range of fork lengths*[1] *of 163 walleyes of age groups I to XIII, Lac la Ronge.*

Sexes combined				Males				Females			
Age group	Number	Av. length, inches	Range, inches	Age group	Number	Av. length, inches	Range, inches	Age group	Number	Av. length, inches	Range, inches
I	14	5.7	4.5- 6.8	VI	8	15.1	13.9-16.0	VI	6	15.05	13.7-16.0
II	13	8.0	6.3- 8.9	VII	9	16.7	15.5-17.8	VII	6	17.0	16.1-17.9
III	18	9.7	8.3-10.6	VIII	6	18.0	17.3-18.7	VIII	5	18.7	17.3-19.0
IV	11	11.5	10.1-12.2	IX	6	19.3	18.0-20.5	IX	4	20.2	19.2-20.9
V	10	13.3	11.7-15.1	X	9	20.6	19.5-22.0	X	7	21.8	19.7-23.0
VI	14	15.1	13.7-16.0	XI	7	21.8	20.3-23.4	XI	5	23.2	21.4-23.1
VII	15	16.8	15.3-17.9	XII	5	22.9	22.0-23.9	XII	5	24.4	23.0-24.8
VIII	11	18.3	17.3-19.0	XIII	5	24.0	23.4-25.2	XIII	4	25.5	24.7-26.0

[1]To convert fork to total lengths use fraction 1.05.

Nipigon (Hart 1928) and Gogebic (Eschmeyer 1950) grew slightly slower. The slowest growth recorded for this species appears to be that in Lake Abitibi (Hart 1928) which is much farther south than Lac la Ronge, but in a region of equally low mean summer temperatures (63°F. in July). In the Great Lakes, walleyes from Lake Erie (Adamstone 1922) grew slightly faster than those of Lac la Ronge, and those from Saginaw Bay, Lake Huron grew slower in 1926 but faster in 1943 (Hile 1954). In spite of its northern location, the average length of mature walleyes in Lac la Ronge is only slightly (about 5 percent) shorter than the average for all waters in the 16 areas reported by Eschmeyer 1950.

The length-weight relationship for walleyes from Lac la Ronge has been derived from measurements of 375 individuals taken in gill nets throughout the period June to September. The average weights for representative fork lengths are as follows:

Fork length inches	Average weight ounces	Fork length inches	Average weight ounces
8	2.9	18	36
10	4.5	20	48
12	9.0	22	61
14	16.3	24	79
16	26.0	26	101

The range of variation of fish of the same length was rather large, often 20 percent heavier or lighter than the averages indicated above. There was no significant difference in the length-weight relations of males or females except in the spawning period, when females were heavier for the same length than males. Samples from the main lake, from the Montreal River spawning run and from the Potato River spawning run showed identical length-weight relationships. However, a sample from Pickerel Bay off Hunter Bay, more than 30 miles east, averaged about 14 percent lighter for equivalent lengths than those from the main lake. The inclusion of a large number of these slimmer fish from Pickerel Bay in a sample measured in 1948 is responsible for the discrepancy between average weights published in an earlier paper (Rawson and Atton, 1953) and the corrected averages listed above.

The relation between length and weight of walleyes from Lac La Ronge is similar to that reported by Carlander for Lake of the Woods (1945) and by Hile (1954) for Saginaw Bay, although the Saginaw Bay fish were somewhat lighter in the size range 14 to 18 inches. Kennedy's (1949) sample from Lake Manitoba averaged about 15 percent heavier than walleyes of the same length in Lac la Ronge and samples from Ile a la Crosse and Peter Pond Lakes were heavier by a similar amount.

Food of Walleyes

In the years 1948 to 1955, 716 walleyes caught throughout the summer, were examined for stomach contents and of these 440 (61 percent) were

empty. In the remaining 276, fish made up 97 percent of the stomach contents. About one-third of the fish material in the stomachs was not identifiable but the remainder was analyzed. Ciscoes *Leucichthys sp.* contributed 56 percent of the volume, ninespine sticklebacks *Pungitius pungitius* 31 percent, white suckers *Catostomus commersoni* 7 percent and yellow perch *Perca flavescens* 1 percent. The remaining 5 percent included small numbers of whitefish, walleyes and spottail minnows *Notropis hudsonius*. The non-fish material, only 3 percent of the diet, was ma n'y amphipods *(Gammarus)* with occasional crayfish and caddis, mayfly and stonefly larvae.

In several lakes of the Upper Churchill drainage (Rawson 1957) the food of walleyes was similar to that of Lac la Ronge but with more yellow perch and moderate quantities of chironomid larvae. Yellow perch and mayfly nymphs were common in the stomachs of walleyes in lakes of the Prince Albert Park, and perch along with chironomid larvae in those from Last Mountain Lake in the southern part of Saskatchewan. Eschmeyer (1950) in a summary of the food of walleyes from some thirty localities in Canada and the United States, shows the yellow perch as the most common food item. As suggested above, considerable quantities of perch are eaten by walleyes in various lakes of Saskatchewan, but in Lac la Ronge the main fish foods were ciscoes and ninespine sticklebacks. The yellow perch made up only 2 percent of the catch in gill nets of suitable mesh size set in Lac la Ronge. Thus its scarcity in walleye stomachs would appear to be simply a matter of availability.

The number of walleyes caught in their first year of life was not large enough to warrant any generalizations as to their food. It was clear, however, that they began eating fish at a very early stage. Stomachs of walleyes 2 to 2.5 inches long, in late July, contained unidentifiable fish remains and two specimens 3 and 3.5 inches long had eaten smaller walleyes. Young-of-the-year walleyes had been eaten by a one-year-old walleye caught July 17, 1948. Cannibalism appears to be uncommon in this species but Eschmeyer (1950) reports finding 5 young in the food of 78 one-year-old walleyes from Lake Gogebic. Other food items found in the stomachs of young Lac la Ronge walleyes were caddis larvae, amphipods and snails.

Parasites

A number of external and internal parasites were collected from the walleyes of Lac la Ronge but no evidence was obtained of harmful effects to fish or man.

The large tapeworm, *Triaenophorus stizostedionis* Miller, was found in the intestine of many of the walleyes examined. A smaller species *Proteocephalus luciopercae* Wardle, was found occasionally in the pyloric cacca. An unsuccessful search was made for pleroceroid larvae of *Dibothriocephalus latus* L. in the flesh of the walleye although adults of this species have been recovered from the intestine of sleigh dogs in this

area. Encysted larvae had been found by the writer in walleyes from Reindeer Lake, which is also in the Churchill River drainage.

The most frequent external parasite of the walleye were the fish leeches, *Piscicola punctata Verrill* and *P. geometra* L. A few specimens of the so-called "fish louse," a parasitic copepod, *Argulus stizostethi* Kellicott, were collected.

Population Density

It would be difficult, if not impossible, to measure a walleye population scattered unevenly over a lake of 550 square miles. Our limited tagging program was designed to explore the movements of two spawning runs and was in no way suitable for estimating the population. Nevertheless there are available several sources of indirect evidence as to the magnitude of the walleye population. These include a sustained commercial production, anglers catches as revealed by creel census, tests with standard gangs of gill nets, and deductions from the strength of the spawning runs.

In the years 1922 to 1949 the annual commercial catch of walleyes from Lac la Ronge averaged 23,000 pounds, or 7 percent of the total production (Rawson and Atton 1953). In the five years 1945 to 1949 the annual commercial average was 55,000 pounds and succeeding years showed no indication of depletion.

The creel census on Lac la Ronge is discussed below in relation to the management program. It has shown that the average annual catch by anglers in six years (1950-1955) has been 42,000 pounds. In the same period commercial fishing for walleyes has been prohibited but a small quantity is caught unavoidably along with the whitefish. This has averaged about 2,300 pounds per year. Thus the anglers' catch combined with the small commercial catch is still well within the 1945-49 average commercial production.

Standardized gangs of gill net made up of 50 yards each of 1½, 2, 3, 4, 5 and 5½-inch stretched mesh have been widely used in lakes of Saskatchewan and elsewhere in western Canada during the past 25 years. Set throughout the season, in all parts and at all depths in a lake, these nets provide a crude measure of the catchable population of fish. The results of some 248 standard gang sets in Lac la Ronge in the years 1948 to 1955 show an average of 155 fish and 148 pounds per set. In these catches the walleyes made up 2.8 percent of the numbers and 4.5 percent of the weight. Comparative data from three large lakes in northern Saskatchewan, Athabaska, Cree and Reindeer, show average catches of 70 to 105 fish weighing 60 to 105 pounds and of these less than 2 percent were walleyes. In four lakes of the Upper Churchill drainage, Big and Little Peter Pond, Churchill and Ile a la Crosse, the average catches were 100 to 250 fish weighing 105 to 280 pounds and including 5 to 16 percent walleyes. Gill-net data from Last Mountain Lake showed an average of 115 fish, 144 pounds and 10.3 percent walleyes. Thus Lac la Ronge appears to have a walleye population heavier than those of large

lakes farther north in Saskatchewan, but considerably lighter than those of lakes in the Upper Churchill area and in the southern part of the Province.

Studies of the spawning runs reported above (Table 1) indicate annual numbers of about 15,000 in the Montreal River and 25,000 in the Potato River. Another large run enters the Nemeiben River, about 30 miles northeast from the La Ronge townsite. At least three other major and four or five smaller runs have been reported by Field Officers and other reliable observers. Thus a minimum estimate of the total annual spawning runs of walleyes at Lac la Ronge would be in the order of 150,000 individuals.

Movement of Walleyes

The walleyes of Lac la Ronge show several kinds of mobility. Of these the spawning migration is the most obvious and best understood. Some progress has been made also in defining the nature and extent of movements in the lake during the summer and of diurnal variations in activity. Each of these kinds of movement affects the availability of walleyes to the angler. At times of inshore concentration following spawning, walleyes may be undesirably easy to catch, while scattering in late season is so complete that the anglers give up walleye fishing to pursue other species. For management purposes it is important to know whether the different spawning runs mix freely in the open lake or whether they are somewhat discrete populations, some of them more vulnerable to angling than others. Thus knowledge of walleye movements has practical importance as well as intrinsic biological interest.

The spawning run of walleyes in the Montreal and Potato Rivers was indicated above as beginning, in different years, between April 17 and May 6. Traps have been placed in the Montreal River, through the ice, as early as April 15, in 1952 and April 11 in 1955. Small numbers of walleyes were caught moving upstream at these early dates. For example, between April 15 and 29, 1955, an average of 13 walleyes per day were caught in the Montreal River trap. During the same period in 1952 the daily average was 47. These fish were almost all males and not yet in spawning condition. The true spawning movement began a few days after the ice broke in the rivers and in Potato Lake (Table 1). It is assumed that the run is stimulated by the inflow of river water which was 4 or 5°F. warmer than that of the lake. The walleyes entered the streams in large numbers from 15 to 30 days before the ice on Lac la Ronge was completely broken.

The movements of walleyes in the region above the stream traps is known in a general way from the recovery of tagged fish. Less than one-quarter of the runs were needed for spawn taking and the remainder was allowed to proceed upstream, although delayed sometimes for a day or two. Those passing up the Montreal River presumably spawned in the river, in Bigstone and Egg lakes and in tributaries thereof. Many of the

tagged fish from this run were caught in domestic gill nets during the summer (see below) but some returned to Lac la Ronge and were caught there by anglers, from one to two months after spawning. Some of the walleyes of the Potato River system were observed spawning in Potato Lake, but very large numbers entered Highway Creek and other small streams. Many walleyes from the Highway Creek trap were caught in Potato Lake within the three weeks following tagging and a few in Lac la Ronge near the mouth of the Potato River after a period of about one month. Th Montreal River run, having access to large lakes above, was much slower in coming downstream than that of Potato Lake. In a general way these data support the observation of Eddy and Surber (1947) that the adults stay upstream from 3 to 6 weeks after spawning.

The preponderance of male walleyes in the spawning run and the approximately equal numbers of the sexes in the lake population has been referred to above. Some evidence of the slow return of the males was obtained in the catch from 56 sets with standard gang gill nets set in the open lake during the summer of 1955. The numbers of males and females caught in each month were as follows:

	Males	Females	Ratio :
June	11	28	1 : 2.5
July	17	32	1 : 1.9
August	68	54	1 : 0.8
September	31	28	1 : 0.9

It would appear that many of the male walleyes had not returned to the lake in July but in August the normal sex ratio was restored.

The distribution of walleyes during the summer in Lac la Ronge is characterized by the gradual return of the spawning runs and early summer concentration inshore, followed by wide scattering into deeper water in August and September. Continued gill netting in 1954 and 1955 has provided information concerning these changes. In 78 sets with our standard gang of nets 543 walleyes were taken. The sets have been divided into those made inshore, *i.e.* within one mile of shore and in depths mostly less than 10 meters; and those in the offshore area, *i.e.* from 2 to 10 miles out and in depths mostly from 12 to 22 meters. Results of this analysis are presented in Table 3 where the average number of fish per set and average fork lengths are shown for June, July and August. September data were too few to justify the calculation of averages. In June the average number of walleyes per set was 5.8 inshore and 2.4 offshore. The inshore catch would have been higher had the nets been set very close to shore where the anglers were making heavy catches at this season. Some domestic nets were set at the shoreline and took very heavy catches of walleyes. In July the average catch was 9.2 inshore and 2.0 offshore but in August the offshore catch had increased to 6.8, nearly equal to that taken inshore, 7.0. The walleyes taken offshore in June averaged only 13.2 inches fork length. Many were immature and presumably few

TABLE 3.—*Numerical distribution and average size of walleyes caught in 78 inshore and offshore gill-net sets, Lac la Ronge, 1954 and 1955.*

	Average number of walleyes per set		Average fork length (inches) of walleyes	
	Inshore	Offshore	Inshore	Offshore
June	5.8	2.4	17.4	13.2
July	9.2	2.0	18.1	15.3
August	7.0	6.8	17.1	17.5

or none had taken part in the spawning migration. In July, with the arrival of more mature fish, the average length of walleyes caught offshore was 15.3 and in August 17.5. It would seem therefore that by August the walleyes were fairly uniformly distributed over the whole lake and that a "normal" proportion of mature fish had returned to the offshore or open-water area.

The depth distribution of walleyes caught with gill nets in Lac la Ronge during 1954 and 1955 has been calculated, Table 4. The average catch per set diminished from 11.3 in the upper five meters (16 ft.) to 1.1 below 20 meters (61 ft.). The great majority of the walleyes were caught at depths less than 15 meters (49 ft.). This was the average for the whole summer; however, as suggested by Table 3, most of the walleyes caught in deep water were taken in August.

TABLE 4.—*Average catch of walleyes at different depths throughout the summers of 1954 and 1955 in Lac la Ronge.*

Depth, meters	Number of net sets	Total number of walleyes	Average number of walleyes per set
0- 5	7	79	11.3
5-10	29	261	9.0
10-15	21	149	7.1
15-20	13	45	3.5
20-22.5	8	9	1.1
All depths	78	543	7.0

Water temperatures one meter above the bottom, and at both ends of the net, were taken for most of the gill net sets in 1954 and 1955. Thus the number of fish caught in water of each temperature may be recorded as follows:

Degrees C.	10	11	12	13	14	15	16	17	18	19	20
Total walleyes caught	0	16	2	41	6	52	167	80	45	0	9
Number of sets	3	2	3	4	3	6	18	12	6	4	3

We have no evidence that the walleyes selected, or moved into, water of any particular range; however, it is evident that they tolerated and were active in the range from 15 to 18°C. (59 to 64.5°F.). It has been sug-

gested that the midsummer movement offshore and into deeper water may be to avoid the high temperatures which develop in shallow water at this time. However, the August water temperatures at 5 to 10 meters in Lac la Ronge are usually between 16 and 18°C. (60.8 to 64.4°F.). Surface temperatures rarely exceed 19°C (66.2°F.) except in shallow, protected bays. Thus it would seem unlikely that temperature preference is the reason for movement into deep water. An alternative suggestion is the pursuit of some food organism. In this connection it is of interest that the ciscoes, shown above to be the largest item in the food of walleyes, are numerous in depths of 15 to 20 meters during August.

The winter distribution of walleyes in Lac la Ronge is known from reports of commercial fishermen who operate nets through the ice. Observations over many years and specific tests made during March 1955, show that walleyes are almost absent from the deep, open-water areas from January to March. During this period they can be caught in considerable numbers in the more shallow, bay areas.

Diurnal variations in walleye activity were tested briefly in 1954 when a standard gang was lifted every 4 hours and reset at once over a period of 48 hours, September 4 and 5. While the numbers caught in the 4-hour periods were small, it was observed that 22 walleyes were caught in the two nights, 8 p.m. to 8 a.m., while only 2 were caught during the day, 8 a.m. to 8 p.m. In 1955 day and night sets were made lifting the resetting each morning at 7 a.m. and again each evening at 7 p.m. over a period of 4 days, August 26 to 30. All sets were made within a half-mile circle in a depth of 10 to 11 meters. The total catch of walleyes and other species was as follows:

	Four 12-hr. "night" sets	Four 12-hr. "day" sets	Ratio day to night catch
Walleyes	17	2	1 : 8.5
Pike	10	6	1 : 1.7
Yellow perch	3	9	1 : 0.3
White suckers	22	17	1 : 1.3
Longnose suckers	64	16	1 : 4.0
Lake whitefish	253	28	1 : 9.0
Ciscoes	268	8	1 : 33.5
Burbot	3	0	

The walleyes were again found to be much more readily caught at night than in the daytime. This agrees with the results of Carlander and Cleary (1949) in Lake of the Woods and Carlander (1953) in Clear Lake, Iowa. It is assumed that the difference in catch is an indication of greater activity at night rather than greater ability to avoid the nets during the day. Support for this reasoning comes from the yellow perch which is known from direct observation to be more active during the day, and to some extent from the white sucker and northern pike which are

also fairly active during the day. Unlike the white sucker, the longnose sucker was much more active at night. The greatest difference in activity was shown by the whitefish and ciscoes, corroborating the observations of Hart (1931) on Lake Nipigon. Presumably the very high night catches of ciscoes indicate that they are feeding actively during this period. Walleyes are also much more active at night and, as indicated above, ciscoes provide more than half the food of walleyes in Lac la Ronge. The greater activity of walleyes at night agrees with the anglers' experience of good morning and evening catches of this species on Lac la Ronge.

Tagging of walleyes in Lac la Ronge was carried on from 1951 to 1955 to obtain information concerning their movements and especially to test the degree of mixing of the spawning runs in the Montreal and Potato Rivers. Fish for tagging were taken from the traps used by the spawn-taking crews. In 1951, 1952 and 1954, walleyes were tagged and released in the Montreal River about one-eighth of a mile above the lake (Figure 1). In 1954 and 1955 they were tagged on Highway Creek, tributary of Potato Lake, and in Potato Lake respectively. Numbered Peterson tags with discs of white plastic, 12.5 mm. diameter, and nickel pins were used throughout. They were inserted rather deeply through the muscle below the dorsal fin.

The number of walleyes tagged and the number recovered in each year up to and including 1956 are shown in Table 5. Of 1,312 tagged in the four years 268 or 21.2 percent have been recovered. This is regarded as a satisfactory rate of recovery. Smith *et al.* (1952) recovered 16 per cent of walleyes tagged in a three-year program on the Red Lakes, Minnesota. Carbine and Applegate (1946) recovered 19 of 100 walleyes tagged in Houghton Lake, Michigan and Rose (1949) recovered 28 percent of 556 walleyes tagged in Spirit Lake, Iowa. The rates of recovery in Lac la Ronge ranged from 15.1 percent for those tagged in 1954 to 34.3 percent of those of 1951. The high percentage recovery in 1951 was largely the result of persistent interviewing of Indians fishing with domestic nets on Bigstone and Egg Lakes. Had this been done in 1954 a larger recovery would have ben made but it was considered more profitable for the field worker to concentrate on Lac la Ronge. The tags held well and appeared to cause no damage to the fish. All walleyes were measured when tagged and those which could be measured after recovery had made "normal" growth as compared with that of untagged shown in Figure 3. Three tagged individuals were recaptured a year after tagging and again during the second year. One of these, a male bearing the number 6167, appeared in the spawning runs of 1954, 1955 and 1956 at Potato Lake. Table 5 shows that many tags were recovered in the year of tagging and in the second and third years. A few were recovered in the fourth and one in the fifth year after tagging.

A great majority of the walleyes tagged at Lac la Ronge were recaptured close to the point of tagging. Of 281 recaptures 190 or 67.5 percent were

within two miles of the tagging site, 43 (15.3 percent) were within 2 to 5 miles, 35 (12.5 percent) 5 to 10 miles, 8 (2.9 percent) from 10 to 20 miles and 5 (1.8 percent) from 20 to 65 miles. Of the first group, taken within 2 miles of the tagging site, approximately one-half were caught one year after tagging in the spawn-taking traps. Since many of the tagged fish taken by angling and in experimental gill nets had gone 5 to 20 miles out into the lake, it may be assumed that most of those caught in the spawn traps had travelled considerable distances and returned to the spawning streams.

Eschmeyer (1942) recovered four walleyes tagged in the Norris Reservoir at an average distance of 4.8 miles. Most of those tagged in Houghton

TABLE 5.—*Walleyes tagged and recovered in Lac la Ronge, 1951 to 1956.*

Walleyes tagged		Tagged fish recovered in the years						Total recovery	Percent recovery
Year	Number	1951	1952	1953	1954	1955	1956		
1951.....	324	84	23	2	2	0	0	111	34.3
1952.....	87	—	7	3	7	2	1	20	23.0
1954.....	576	—	—	—	40	29	18	87	15.1
1955.....	278	—	—	—	—	22	28	50	18.0
Totals.....	1265	84	30	5	49	53	47	268	21.2

Lake, Michigan by Carbine and Applegate (1946) were recovered at an average distance of 3 miles but three had gone 130 miles downstream. Doan (1942) recovered 22 specimens in western Lake Erie, most of them about 20 miles away but one had gone 200 miles to the east end of the lake. The average distance between the tagging site and the point of recovery at Lac la Ronge was 3.5 miles and one specimen had gone upstream 65 miles. Thus the general pattern seems to be a rather limited movement in walleye populations but with a few long-distance wanderers.

Most (65 percent) of the fish tagged in the Montreal River were caught in the bay close to the townsite of La Ronge, or in Bigstone Lake, Figure 1. A smaller number (14 percent) had gone farther out into the main lake or farther upstream into Egg Lake (8 percent). Most of those tagged in the Potato River system were caught in Potato Lake or along the adjacent shore of Lac la Ronge. Another 15 percent of these had gone farther east into the open water of the main lake.

The five walleyes which were captured more than 20 miles from the site of tagging are of special interest although they represent a very small percentage of those recovered. One, tagged in the Montreal River on April 28, 1954 was recovered 77 days later near the north end of Montreal Lake having travelled 65 miles, through Bigstone and Egg Lakes and up the Montreal River. A second, tagged at the Montreal River in May 1951, had travelled right across Lac la Ronge and Hunter Bay to be recaptured

on July 10 in Pickerel Bay nearly forty miles away. In the same year a specimen tagged on the Montreal River was recaptured at Nemeiben River, 22 miles northwest. A walleye tagged at Potato Lake May 15, 1955 was recaptured on June 30, 1955 in Hunter Bay 30 miles east. Another, tagged at the same time and place was recaptured on August 17, 1955 among the islands 22 miles east of La Ronge townsite. Two other specimens had travelled 16 miles miles across the lake to Fox Point, and 12 miles northeast to Nut Point, respectively. All of these distant recoveries were males but it should be noted that the number of males tagged was nearly three times that of females.

Evidence from recovery of tagged walleyes suggests that the spawning runs in the Potato and Montreal rivers represent populations which, although they may mingle while in the lake, tend to separate again at the spawning period. Of 199 recoveries from walleyes tagged on the Montreal River only one was caught in Potato Lake and River. Of 68 recoveries among walleyes tagged on the Potato River system only four were caught in the bay where the Montreal River enters Lac la Ronge and none in the river itself nor in Bigstone or Egg lakes. This situation and the general observation that about 70 percent of the recaptured fish were taken within 2 miles of the point of tagging, suggests that attention may have to be given to the conservation of individual sub-populations or spawning runs.

Management

In order to plan for the utilization and conservation of a fish resource it would seem essential to have some knowledge of the magnitude of the population available for use. The tagging program was not designed for estimating the walleye population of Lac la Ronge but we have other sources of evidence, namely past commercial production and the results of systematic test netting. It was indicated above that the annual commercial production of walleyes in Lac la Ronge from 1922 to 1950 was 23,000 pounds per year and in the five years up to and including 1950, the average was 55,000 pounds. The program of test netting, described above, indicated that Lac la Ronge had a heavier walleye population than lakes farther north in Saskatchewan where walleyes averaged less than 2 percent of the standard gang catch. However, lakes in the Upper Churchill drainage, and in southern Saskatchewan had still greater populations, with the walleyes averaging 5 to 15 percent of the catch.

The utilization of walleyes by angling in the past six years has been shown by our creel census (Table 6) to have ranged from 24,000 to 49,000 pounds averaging 41,000. This is well above the long-term commercial production but somewhat less than that of 1946 to 1950. Thus the present anglers' catch cannot be considered excessive. Moreover, it is highly probable that walleye populations in the more remote parts of Lac la Ronge have been fished less heavily than those adjacent to the Montreal River and Potato River, yet judging by the strength of the spawning runs, these

two populations have suffered no serious decline.

Some control of utilization of the walleyes is accomplished by the daily catch limit. In 1952 this was reduced from 10 to 7 fish per day and an aggregate poundage limit of 15 pounds plus one fish was introduced. The uncontrolled factor is, of course, the number of anglers. This rose (Table 6) from 3,500 per year in 1950 to 7,000 in 1953 but shows signs of levelling off in the neighborhood of 5,000 partly as a result of increasing numbers of anglers flying from La Ronge to little fished lakes farther north. The percentage of walleyes in the anglers' catch was from 16 to 18 except in 1954 when unusual weather kept the trout fishermen away from the best grounds and a higher proportion of walleyes was taken. The relative constancy of the walleye catch over the six-year period would suggest that the stock was being given adequate protection.

TABLE 6.—*Summary of results of creel census on Lac la Ronge, 1950 to 1955.*

	1950	1951	1952	1953	1954	1955
Number anglers	3,500	5,700	6,250	7,000	4,700	4,800
Catch, pounds	204,000	280,000	251,000	278,000	205,000	144,000
Catch, pounds/acre	0.68	0.93	0.83	0.92	0.68	0.48
Percent Composition						
Pike	52	60	63	64	57	61
Lake trout	32	24	19	19	17	22
Walleyes	16	16	18	17	26	17
Catch per angler per trip						
Number of fish	13.5	11.0	9.0	9.3	12.3	8.6
Pounds of fish	54.4	52.5	40.1	39.7	43.6	30.0
Average weight per fish	4.0	4.8	4.5	4.3	3.5	3.5

After careful investigation, it was decided that Lac la Ronge should be managed primarily for its game fish production, but that a controlled commercial fishery was desirable in order to make use of the whitefish population (Rawson and Atton, 1953). During the past five years an average of 180,000 pounds of whitefish has been taken and during this operation an average of 2,300 pounds of walleyes. The seasonal movements of the walleyes make it relatively easy to avoid taking any significant amount along with the whitefish. It has been more difficult to avoid taking undesirable amounts of lake trout.

At present only one mink farm is operating at Lac la Ronge and sufficient offal is obtained at the filleting plant and from the tourist outfitters to feed these animals. If mink farming expands in this area it may be necessary to allow gill-netting to obtain the necessary food. Even if this occurs, it is not anticipated that there will be any difficulty protecting the walleye population since, in other parts of the Churchill drainage, mink farmers tend to avoid taking this species.

The domestic net fishery practiced by Indians and other residents for human and dog food provides a problem in management. It has proved impossible to obtain reliable data as to the extent of this fishery, but it has been estimated as between 100,000 and 150,000 pounds per year, chiefly in the regions of the Montreal, Potato and Nemeiben Rivers. Walleyes contribute a considerable fraction of this catch. In 1951 and 1952 more than 80 percent of the walleyes recovered after tagging in the Montreal River were caught in domestic nets (Rawson and Atton 1953). This is regarded as a weak point in the scheme of walleye management and further efforts should be made to measure this production.

The creel census is a most important basis for management of the game fishery in Lac la Ronge. Table 6 indicates that the walleye fishery is standing up to heavy angling utilization. While the pike are taken in greater quantity and the lake trout has greater prestige as a game and trophy fish, the walleye has an important place in the game fish production. In the early part of the season the walleye usually bears the brunt of angling at Lac la Ronge.

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USE OF LOUVERS FOR GUIDING FISH

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ABSTRACT

Late in 1951, the U. S. Bureau of Reclamation completed construction of the world's second largest pumping plant at Tracy, California. In connection with this project, it was found that facilities would have to be installed to prevent fish of several species and as short as 10 millimeters from passing into the pump intakes.

Because of the magnitude of the project and lack of knowledge as to the best protective facility, a test structure with several types of fish screens was installed. Fish stopped by the screens were collected by a port and riser system. Tests revealed that none of these facilities adequately met fish protection requirements at Tracy. It was therefore necessary to consider other methods. Research by members of a team from the U. S. Fish and Wildlife Service and the Bureau of Reclamation developed a louver system for guiding fish.

The louver system consists of a fence-like series of vertical steel slats set with their broad faces at right-angles to the direction of flow and placed across the channel in a diagonal line terminating at a narrow by-pass. When fish approach the louver slats, particularly when water velocities are high, they tend to avoid them and swim away at an angle of about 90 degrees. In maintaining this position, they place themselves somewhat broadside to the approach flow and are carried downstream, through the by-pass and either into the main stream or a holding pond.

Efficiency studies of louvers in a test flume and in the pilot structure indicated that striped bass, salmon, shad, catfish, and other species can be successfully diverted and collected by this system.

INTRODUCTION

As a part of the Central Valley Project in 1951 the U. S. Bureau of Reclamation completed a water diversion of some 4,600 cubic feet per second from the Sacramento-San Joaquin Delta near Tracy, California. The magnitude of this diversion created many difficult problems relative to fish protection.

Study of the Delta fisheries resources by the California Department of Fish and Game and the U. S. Fish and Wildlife Service, preceded the construction of the diversion. During the period 1946 to 1949, the

Service, with the cooperation of the Bureau of Reclamation, carried on investigations in the Delta to determine: (1) the magnitude, composition, and occurrence of the various fish populations, (2) the effects of changing hydrodynamics, and (3) means for protecting the fish populations from possible damage which might result from pumping plant operations (Erkkila, *et al.*, 1950).

The present paper deals with the development and testing of louver systems for guiding fish so that they are not drawn into the water intakes of the pumping plant and with application of experimental findings to a permanent louver system at Tracy.

Description of the Tracy Diversion Project

The Sacramento River joins the San Joaquin River in what is known as the Delta Area. Here both rivers move through complex network of canals to form the uppermost extension of San Francisco Bay. Within the Delta, waters of the two rivers mix and are influenced by tides in their lower reaches.

The Tracy Pumping Plant, which provides water for the Delta-Mendota Canal, is located approximately 10 miles from the City of Tracy. A diversion canal from Old River, one of the many channels and sloughs within the Delta, extends 2.3 miles to the pumping plant. Here are six large pumps of the second largest pumping plant in the world. These pumps have a normal capacity of 4,600 cubic feet per second and lift water a vertical distance of 197 feet to the Delta-Mendota Canal.

Flow into the intake canal is a function both of number of pumps in operation and tidal action. Effect of tides can be considerable and may increase the flow as much as 400 cubic feet per second at the highest rate of tidal inflow. Including tidal flow the maximum flow into the canal, which must ultimately pass through a fish screening structure, may reach 5,000 cubic feet per second.

A diversion of this magnitude has a pronounced effect on flow patterns of canals within the Delta. Because of this the Bureau of Reclamation constructed the Cross-Channel Canal on the lower Sacramento River to increase the flow of water toward the diversion. Flow generally is from the northern to the southern side of the Delta and toward the Tracy Pumping Plant. This results in reduction of flow toward the ocean. Oceanward flow varies considerably during the year and to some extent from year to year depending on flow of tributary river systems and amount of water diverted.

During July and August, diversion of water by the Bureau of Reclamation and others within the Delta accounts for the entire flow (900 second-feet) of the San Joaquin River and 52 percent (6,400 second-feet) of the flow of the Sacramento River. It is not unusual for the flow of the San Joaquin River at its confluence with the Delta to be zero during the late summer months, and all water then diverted from the Delta

must be obtained from the Sacramento River. Such a flow pattern results in attraction and concentration of fish in the vicinity of the pumping plant.

Fish Population Affected

The Sacramento-San Joaquin Delta is a very important area for anadromous and other fish. Here there are at least 23 species, of which more than half have been collected at the pilot screening structure. Primary consideration is given to the protection of four species: king salmon *(Oncorhynchus tschawytscha)*, striped bass *(Roccus saxatalis)*, American shad *(Alosa sapadissima)*, and white catfish *(Ictalurus catus)*.

King salmon pass through the Delta area during upstream and downstream migration. It is important to consider the time of appearance of fingerling salmon in the Delta in relation to operation of the Tracy pumps. Irrigation requirements vary from year to year with rainfall and natural water storage, but year-around pumping may be expected. Previous studies indicate that the bulk of the Sacramento River salmon migrate seaward during February, March, and April with a peak during March. Following this is the migration of salmon fingerlings from the San Joaquin River in April, May, and June, with a peak in May. There are years, however, when migrant salmon fingerlings are in the area both before and after the periods mentioned. Therefore it is necessary to protect these fish at Tracy throughout the entire first half of the year.

Size range of seaward migrating king salmon in the Sacramento River is from 1.5 to 3.3 inches.

Striped bass have extensive recreational value for sportsmen and have been a cause of concern from the standpoint of water diversions. Spawning season is usually during April, May, and June, with a peak during the last week of April through the middle of May. Water temperatures influence spawning time.

The entire Delta area including the lower portions of the Sacramento, San Joaquin, and Mokelumne Rivers is used by striped bass for spawning. By the end of September, most of the striped bass have left the Delta. It appears, therefore, that the young striped bass will be influenced by diversion at Tracy from approximately May through September, a period within peak pumping. No technique has been found which will successfully protect striped bass eggs; but, as will be shown, it is possible to protect striped bass as small as 10 millimeters with a louver system.

Shad support a commercial and a growing sports fishery on both the Sacramento and San Joaquin Rivers. Records of the State of California indicate that the large annual fluctuations of catch are due to economics of the industry and to great change in the shad population. The annual take of shad here is about 600,000 pounds. This species also uses the Delta for reproduction. Spawning occurs in spring. Shad grow rapidly and reach an average length of about 0.8 inches by the end of June.

Each month thereafter they grow about 0.4 inches. Young shad are unusually sensitive and can be killed by handling or disturbing. For this reason, shad have been found to be more successfully handled by louvers than by other types of screens.

Catfish are also abundant and highly favored as a food fish. They are heavily fished and it is estimated that more than 2,000,000 catfish were taken by sportsmen in 1951. Commercial fishing of catfish was halted in 1953 by regulation. The Tracy diversion was considered with concern because of its possible effect on catfish which are year-around residents of the Delta area.

Individually, the other species of fish in Delta waters are of much less importance than any of the four species mentioned. However, as a group, they must be given consideration.

Appraisal of Fish Screening Methods at the Pilot Structure

In 1949 findings of the U. S. Fish and Wildlife Service (Erkkila *et al.*, 1950) were discussed and considered by representatives of the Service, the Bureau of Reclamation, and the State Division (now Department) of Fish and Game. Belt-type traveling screens were then thought to be the only screens which offered a possibility of functioning in the Tracy intake canal. However, because they had never been used in a similar situation and because they were costly, both initially (estimated at $4,500,000) and in operation and maintenance, the Reclamation Service was reluctant to invest in them. In the discussions it was concluded that low initial water demand, uncertainties as to efficiency of belt-type screens and the possibility of a less costly solution to the problem justified experimental work. It was decided to try traveling screens and other types of screens and also to explore new possibilities at a pilot installation built for this purpose. The pilot installation would also serve as an operating screen for the first years while diversion requirements at the pumping plant were increasing. The pilot fish-screen structure was designed in consultation with the California Department of Fish and Game. Construction was completed late in 1951. Because of high water and other conditions test runs could not be made until the following year.

The pilot screening structure was located in a channel which by-passes the main canal intake, thus leaving a site for a permanent fish protection facility on the main canal. The pilot screen is 255 feet long and 25 feet 8 inches deep from the deck to the canal floor. It is divided into 12 bays, each 11 feet 8.5 inches wide. In Bay No. 1 a sloping perforated plate screen, of the type found satisfactory at some locations in California, was installed. Two traveling or belt-type screens, and conventional stationary panel screens of 5-mesh-per-inch hardware cloth were placed in the remaining 9 bays. A fish collecting system, consisting of ports and risers in the upstream face of eight of the piers was included in the original

design. This was to pick up fish as they moved laterally along the face of the screens.

In a short time the sloping perforated plate screen failed because of clogging which could not be prevented by reciprocating wiper blades moving over the upstream face of the screen. It was apparent that perforated plate screens would not be satisfactory at Tracy.

The belt-type screens lifted exhausted fish as well as debris, and both were then washed into a debris collection trough. Very few fish entered the port and riser system either from between the traveling screens or the stationary screens. Use of the port and riser system was therefore abandoned. Attention was then turned to modification of the traveling screens to improve them for salvaging fish. The two traveling screens salvaged fish and were easily cleaned but stationary panel screens were difficult to clean. This prompted installation of four additional traveling screens. Alterations were made to collect the fish from the screens and to separate them from debris. Tank trucks were secured to haul the fish downstream to a point below the influence of the pumps. Originally, it had been planned to use a specially-designed barge to transport the fish downstream, but towing it below the influence of the pumps was slow and costly compared to hauling the fish by truck.

It was found that large numbers of striped bass, salmon, and shad went into a state of shock because of exhaustion from fighting to prevent impingement on the traveling screens. If these fish were left in a fresh-water collection tank, survival rate was low, but with treatment in a saline solution up to 90 percent of the salmon and striped bass revived. Shad did not respond well to this treatment.

Development of Louvers

In this investigation use of louvers was first considered in January 1952, when they were used in a series of experiments at the Coleman Hatchery of the U. S. Fish Wildlife Service. During the same period, the Bechtel Corporation and the Pacific Gas and Electric Company, represented by Mr. James E. Kerr and Associates at Antioch, California, tested the possibility of deflecting fish by somewhat similar means (Kerr, 1935). Louvers and similar devices offered promise for guiding fish out of a channel and into the safety of a by-pass without delaying their downstream movement or causing fright, exhaustion, or shock from physical contact with a screen.

General Description

The louver system, as illustrated in Figure 1, consists of a fence-like series of vertical steel slats. Each louver slat is set at right angles to the direction of stream flow. The louver system is placed diagonally across the canal. Fish, upon approaching the louvers, tend to avoid them and are swept

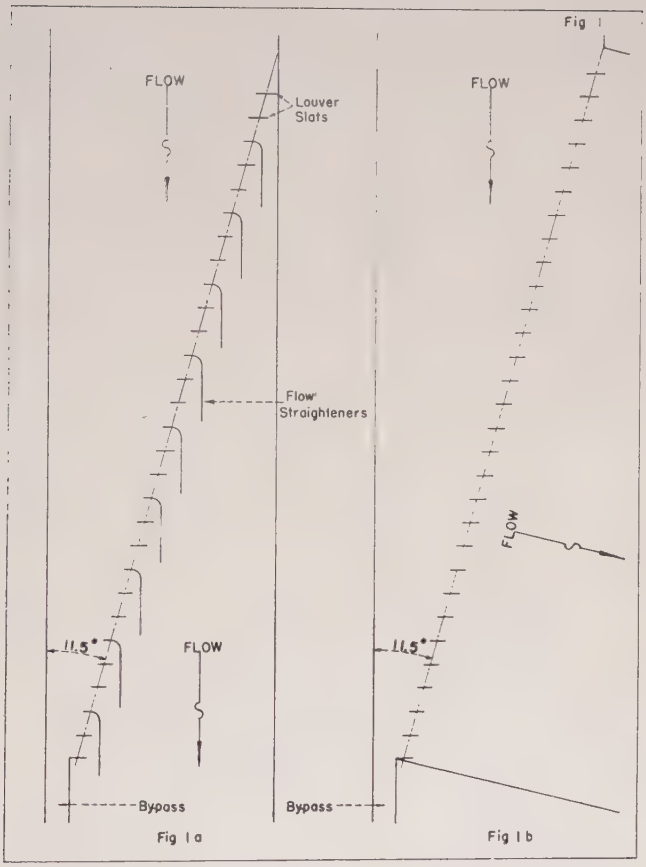


FIGURE 1.—Diagrammatic sketch of a louver structure for guiding fish, showing two acceptable methods of installation.

downstream by the current. At the downstream end, the louver system terminates in a by-pass which the fish enter and follow into a pond or a channel leading downstream. The height of the louver slats is determined by the depth of the channel.

TESTING FACILITIES

In 1952, a flume measuring 36 by 5 feet, with a depth of 2 feet was constructed adjacent to the pilot screening structure. This flume provides controlled conditions for testing development of the louver principle. Water for the test flume was supplied from the holding pond which was originally built to retain fish collected by the port and riser

system of the pilot screen. Two sump pumps with a total capacity of 12 cubic feet per second lifted the water into a header box at the upper end of the flume. Velocities as great as 3.0 feet per second could be attained. In 1954, a test flume with larger pumps was constructed to achieve increased velocities and greater flexibility in testing. The flume allowed inexpensive and rapid changes in such variables as the angle of the line of louvers, angles of the individual louver slats, spacing of slats, and arrangement of flow-straightening vanes. It was necessary to filter the water to observe the behavior of fish in the test flume. Delta water in the intake channel is very turbid and usually has a Secchi disc visibility of 8 to 10 inches.

The test flume also offered opportunity for extension of the testing for several species of fish. Salmon were secured from the U. S. Fish and Wildlife Service Coleman Hatchery for test purposes, prior to the arrival of downstream migrants at the pilot screen. It was also possible to make tests with trout supplied by the California Department of Fish and Game.

By the summer of 1953, the results with louvers in test-flume operation, using salmon and striped bass taken on the traveling screens, were considered sufficiently favorable to justify construction of a larger louver system in Bay No. 1

This louver system was installed at an angle of 11.5 degrees to the flume (referred to as angle Θ). It was designed for water 5 feet deep although the canal depth ranged from 16 to 20 feet, depending on tidal stage. Below the louvers the channel was blocked off and a false bottom constructed. Several considerations prompted the selection of the 5-foot depth. Among them were the high cost of a full-depth structure, difficulty of measuring the efficiency of a deep structure, and the assumption that fish would react the same to louvers regardless of depth if the approach flow was smooth. The latter assumption was later verified for water as shallow as 4 feet deep.

Velocity measurements were taken in Bay 1 at five equi-distant points in a line midway between the line of louvers and the channel wall. The differential in head upstream and downstream from the louvers was measured with staff gauges located 4 feet above and 4 feet below the louvers, and readings were taken each hour during testing. A trash rack was constructed at the entrance to intercept debris.

To test the efficiency of the louvers, individual nets of 1/8-inch nylon bobbinet were installed on the downstream side. Three flow-straightener vanes created four separate downstream channels. The end of each channel fitted into a net. Fish passing through louver slats were thereby confined to a specific channel leading to a separate net. Thus, it was possible to determine fish loss through different sections of the louver system. Both night and day tests were made. Nets were lifted hourly and all fish collected were recorded by species and number. A record was main-

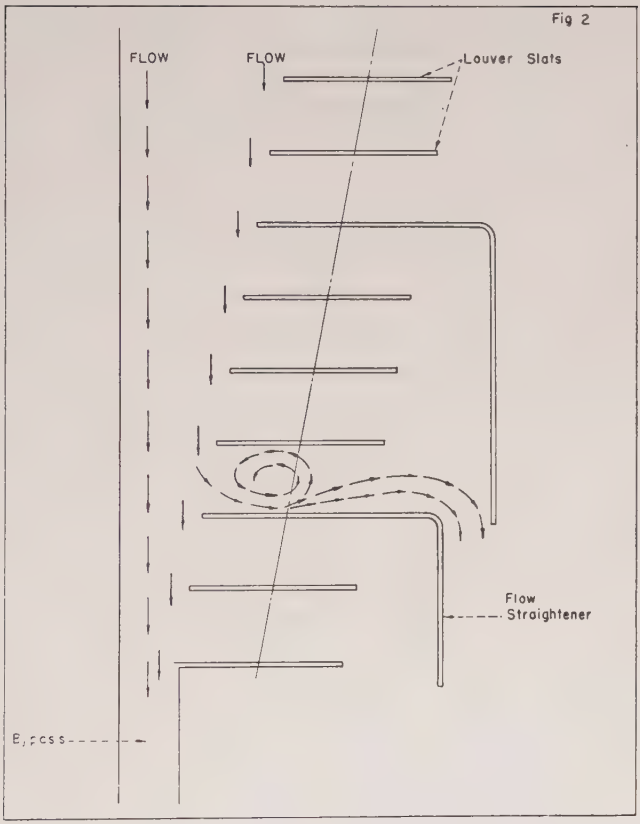


FIGURE 2.—Diagrammatic sketch of water flow through louver system.

tained of fish passing through the louvers indicating their number and specific points of passage.

FLOW PATTERNS

Effect of different velocities of flow toward the louvers was investigated, within ranges of 0.5 to 6.0 feet per second. As water flows downstream and along the louver sections, small portions are progressively sliced off by each projecting louver slat as shown in Figure 2. It is of particular importance that the pattern of flow toward the louvers be even and as free of turbulence as possible. This allows the fish to maintain their orientation in respect to the direction of flow as they approach the louvers.

Louvers are an obstruction and therefore cause loss of head in the channel in which they are placed. Structural material, debris, and accumulations of trash also contribute to head loss. To help reduce this head loss, the spacing between louver slats may be widened, or the slats may be positioned to the flow at less than 90 degrees. Trials with the slats set an angle of 70 degrees indicate that fish are diverted without perceptible change in efficiency.

Besides causing head loss, the louvers divert the flow into a channel at right angles to the main channel when the louver slats are placed at right angles to the direction of flow. To redirect the flow so it again parallels the side of the channel, flow straightening vanes were developed in hydaulic laboratores of the Reclamation Service at Denver. It was found that vanes of the same thickness as the louvers were required and that they should extend to the same depth and be spaced so they overlap. The vanes, attached at right angles to the louvers, also distribute the flow so that each section between vanes passes about the same volume in water. In addition, flow straightening below the louvers influences the flow approaching the louvers by maintaining its initial uniformity.

When a system of louvers without flow straightening vanes is placed at an angle across a channel, a backwater build-up increases progressively upstream until at the upper end of the system very little water flows through. This build-up is reflected by a water velocity increase of nearly 2.5 times from the upstream end of the louvers to the downstream end. With the addition of the flow straighteners the backwater build-up is distributed along the upstream face of the louver system, thereby correcting the non-uniformity of flow. Since the flow straighteners must overlap, length depends upon their spacing.

In the final structure the head loss across the line louvers will be 0.4 foot at the maximum velocity of 4 feet per second.

Louvers and Fish Behavior

At the beginning of the Tracy investigations, one inch was selected as the minimum length of fish that could be salvaged. Both physical and biological factors influenced this selection. Screens fine enough to stop smaller fish would require a very long structure to avoid building up a high head of water. The debris problem would also be greater. Also, at that time it was thought that fish smaller than one-inch would be weak and unable to respond to obstructions or to survive handling. From tests of swimming speed and endurance, it was concluded that one foot per second usually represents the maximum swimming ability of 1-inch striped bass.

The position of a fish moving downstream along a louver system is determined by the size of the fish, the angle of the line of louvers, and the velocity of the flow. At velocities not requiring maximum swimming effort, the usual position taken by a fish moving downstream is tail-

TABLE 1.—*Calculated maximum swimming speed (Vs) of fish passing down a line of louvers in relation to water velocities of approach (Va) and specific angles (θ) of the line of louvers.*[1]

WATER APPROACH VELOCITY—FEET PER SECOND	MAXIMUM SWIMMING SPEED—FEET PER SECOND											
7.0	0.97	1.22	1.46	1.69	1.93	2.16	2.39	2.96	3.50	4.02	4.50	4.95
6.5	0.90	1.13	1.35	1.57	1.79	2.01	2.22	2.75	3.25	3.73	4.18	4.60
6.0	0.84	1.04	1.25	1.45	1.65	1.85	2.05	2.54	3.00	3.44	3.86	4.24
5.5	0.77	0.95	1.14	1.33	1.52	1.70	1.88	2.32	2.75	3.15	3.54	3.89
5.0	0.70	0.87	1.04	1.21	1.38	1.54	1.71	2.11	2.50	2.87	3.21	3.54
4.5	0.63	0.78	0.94	1.09	1.24	1.39	1.54	1.90	2.25	2.58	2.89	3.18
4.0	0.56	0.69	0.83	0.97	1.10	1.24	1.37	1.69	2.00	2.29	2.57	2.83
3.5	0.49	0.61	0.73	0.85	0.96	1.08	1.20	1.48	1.75	2.01	2.25	2.47
3.0	0.42	0.52	0.62	0.73	0.83	0.93	1.03	1.27	1.50	1.72	1.93	2.12
2.5	0.35	0.43	0.52	0.60	0.69	0.77	0.85	1.06	1.25	1.43	1.61	1.77
2.0	0.28	0.35	0.42	0.48	0.55	0.62	0.68	0.85	1.00	1.15	1.29	1.41
1.5	0.21	0.26	0.31	0.36	0.41	0.46	0.51	0.63	0.75	0.86	0.96	1.06
1.0	0.14	0.17	0.21	0.24	0.28	0.31	0.34	0.42	0.50	0.57	0.64	0.71
	8	10	12	14	16	18	20	25	30	35	40	45
	ANGLE OF LINE OF LOUVERS IN DEGREES											

[1]Values underlined in Table represent combinations of approach flow velocities and angles of lines of louvers negotiable by fish capable of swimming at 1.0 foot per second.

first and parallel to the flow with momentary lateral movement away from the louvers as shown in Figure 4a. When velocities exceeded swimming speed, it was observed, particularly from a study of slow-motion movies, that fish orient themselves to the line of louvers at angles from it ranging up to 90 degrees (Figure 3b). The magnitude of the change in orientation is a function of the velocity of flow and the angle of the line of louvers. The velocity vector diagrams in Figure 4 show the relationship of these factors.

In using the vector diagrams to analyze any given set of conditions, the approach velocity may be resolved into two components: V which is parallel to the line of louvers and Va at right angles to the individual louver slats. The component Vs represents the speed at which a fish must swim to overcome the force of component Va and remain at a constant distance from the line of louvers while moving along component V. The swimming speed (Vs) is related to the approach velocity as $Vs = Va \sin \Theta$. Table 1 shows the wimming speeds (Vs) which

a fish must maintain to pass along a line of louvers for selected combinations of approach velocity and louver system angle. For example, a 1-inch fish capable of swimming 1.0 foot per second can maintain position in an approach velocity of 7.0 feet per second at a louver line set at an angle of 8 degrees.

Louver System Arrangement and Dimensions

In considering the design of a louver system, two possibilities for alinement of the louver slats were explored: a straight-line arrangement and a "saw-tooth" arrangement. In certain situations, particularly at a diversion in a stream, the saw-tooth arrangement may be best, for this arrangement has the advantage of compactness and probably lower initial cost. However, it lacks flexiblity and once it is built, all of the by-passes must be used. With a straight-line arrangement, supplementary by-passes along the face of the system may be closed if not needed. Where a minimum diversion of water is essential, the straight-line arrangement is superior. Also, in large installations where the louver sections must be handled with a crane, as at Tracy, the straight-line arrangement is simpler to operate.

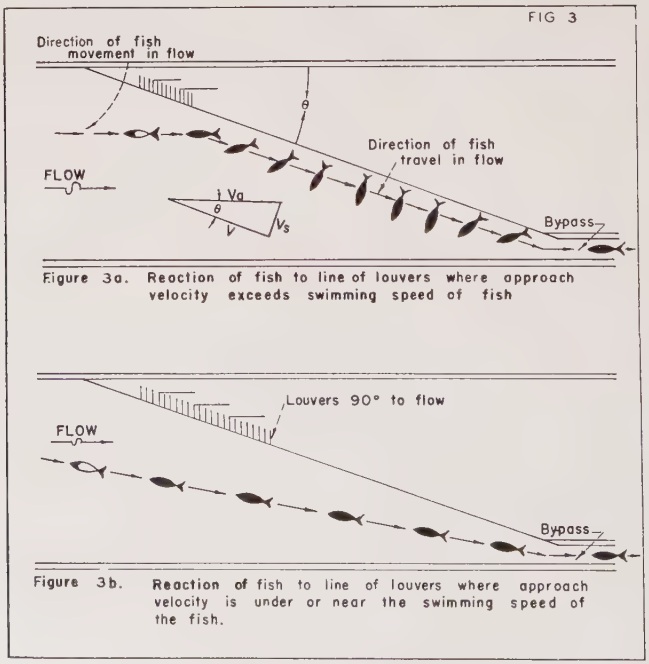


Figure 3.—Reaction of fish to line of louvers.

Trials with louver systems placed at various angles to flow showed that they would deflect fish within a range of angles from 11.5 to 40 degrees, but greatest success was had with smaller angles. Angles to flow greater than 40 degrees provided little or no guidance, and the fish had difficulty finding the by-pass. After the effective range of angle to flow had been established, consideration was given to the length of the louver system. It first appeared that the length of the louver system would be determined, at least in part, from the angle selected by such calculations as are presented in Table 1. However, it was also found that for given values of maximum flow in cubic feet per second (Q Max), swimming speed of the fish (Vs), and average depth of canal (d), the length of the line of louvers (L) could be calculated from the equation:

$$L = \frac{Q\ Max}{Vsd}$$

The values applicable at Tracy are:

Q Max = 4,800 cubic feet per second.
d = 14 feet, the average depth of the channel.
Vs = 1.0 foot per second, swimming speed of fish considered

By substitution of these values in the preceding formula the length of the necessary louver system at Tracy was calculated as:

$$L = \frac{4{,}800}{14 \times 1} = 343 \text{ feet}$$

By-Passes

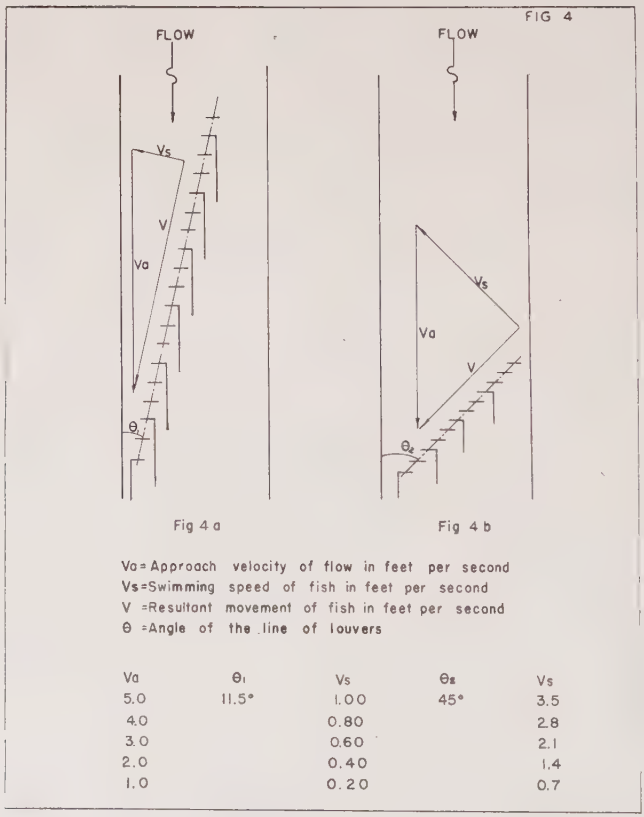
In the first louver experiments, the by-pass width was 6 inches. This proved satisfactory and no change was made until 1955 when a 4-inch by-pass was successfully used throughout the season. In some of the earlier trials, a 2.5 inch by-pass was used. Fish passed through this narrow width without hesitation. For both young salmon and striped bass, the smaller by-passes were satisfactory, but because they were more likely to be clogged by debris, a 6-inch by-pass has been selected for use at Tracy. No advantage was found in a larger by-pass, but by-pass widths up to 18 inches may be necessary with trout. The trout used in trials at Tracy seemed sensitive to factors other than louvers and did not react well to them.

In the discussion on flow straightening vanes, mention was made of the importance of uniformity in flow across the channel as water approaches the louvers. However, it was found that a gradual increase in velocity as flow approaches and enters the by-pass is desirable in diversion of fish. If a reduction in velocity occurs just ahead of or within the by-pass, the fish usually stall in their movement and swim back upstream. The con-

fusion thus created may cause them to move between the louver slats rather than through the by-pass.

Number and Location of By-Passes

After the length of the louver system had been established at 343 feet, there was still some question as to whether very small fish could maintain position along the line of louvers long enough to be diverted into the by-pass at the lower end of the system. Although tests showed that 1-inch striped bass have a swimming speed of one foot per second for 10 minutes, or long enough to pass along a 600-foot louver line, tests were made to determine whether a by-pass along the face of the screen would collect fish. This was done by placing a baffle plate just below a six-



Va	θ1	Vs	θ2	Vs
5.0	11.5°	1.00	45°	3.5
4.0		0.80		2.8
3.0		0.60		2.1
2.0		0.40		1.4
1.0		0.20		0.7

Figure 4.—Vector diagrams illustrating magnitude of swimming effort which must be expended by fish to move parallel to the louver line.

inch opening in the center of the louver system in the test flume used in 1954. The baffle plate extended 3 feet upstream. It was found that in the daytime one-third of the fish used in the tests were collected by the supplementary by-pass while at night two-thirds were collected. In order to provide a maximum factor of safety, it was decided to include three supplementary by-passes in the final design.

Fish Collection and Debris Removal

With four by-passes in the planned louver system the volume of water diverted (up to 120 cubic feet per second) will be greater than can be reasonably handled in holding tanks. Further concentration of the fish is necessary. Also the water in which the fish are concentrated must be free of debris so that the aeration equipment in the tank trucks will not become clogged. Because of these difficulties a secondary louver system has been included in the final design. In this secondary system debris-free water can be introduced into the secondary by-passes to carry the fish to holding tanks.

Dimensions and Placement of Louver Slats

The height of louver slats depends on the depth of the channel in which they are placed. As described in the discussion of the louver system for Bay No. 1, height does not appear to be a factor in efficiency for guiding fish. The first louver slats used were 2.5 inches in width. This width is sufficient for structural rigidity and slats this size function well. Since width was not a problem either in cost or in efficiency of operation and because time was limited, trials with louver slats of other widths were not made. The original louver slats were one-eighth inch thick. Many tests were made with louver slats ranging in thickness from one-eight to one-half inch, but no appreciable difference in efficiency was noted. Thickness, therefore, appears to be a matter of structural requirement. Slats in the planned permanent structure will be 3/16 inch thick.

In most of the testing, louver slats were placed at 90° to the flow. However, trials were also made at 70° and 0° because head loss is less at the small angles. At zero degrees the louvers did not function to divert fish. Although the louver slats appeared to function at 70°, the 90° angle has been adopted for the permanent structure on the premise that the goal is maximum efficiency for fish conservation.

Spacing of slats appears to be related to fish size: the larger the fish, the greater the allowable spacing between them. Table 2 shows the results of spacings up to 3.5 inches. In most of the trials 1- and 2-inch spacing was used. From these trials it appears that 2-inch spacing is as satisfactory as 1-inch for fish of minimum length of 10 millimeters. The amount and kind of debris may also be a factor in spacing. At

TABLE 2.—*Efficiency of louvers for by-passing salmon*[1]. *Slats spaced at 3.5 inches; line of louvers at 16° and by-pass 6 inches wide*

Test Number	Number of fish through louvers	Number of fish through bypass	Percent efficiency	Average water velocity (feet per second)
1	16	95	86	2.2
2	14	122	90	2.0
3	3	129	98	1.9
4	17	375	96	2.5
Totals	50	721		
Mean			94	

[1]Salmon migrants of 71.1 millimeters mean standard length.

Tracy, minute tule fragments are the principle debris and here narrow spacing is possible. Where leaves, sticks and similar debris are present, a wider spacing may be necessary. A conservative 1-inch spacing was selected for use in the planned structure at Tracy because this louver installation is unique and as yet experimental as a major fish conservation facility.

TESTS OF EFFICIENCY OF LOUVER SYSTEM

Following are results of tests with the Bay No. 1 louver made during 1955 to supplement the findings of earlier experimental work.

SALMON TESTS

Although many studies had been made in the test flume with chinook salmon fingerlings, no tests had been made prior to 1955 with salmon within the pumping plant intake canal. The louver installation in Bay No. 1 was therefore readied in the spring of 1955, and tested throughout the salmon migrant season.

The first series of tests was made with louver slats spaced at 3.5 inches and the line of louvers placed on an angle of 16° to the direction of flow. The louver by-pass was 6 inches wide. The test results are shown in Table 2.

A second series of tests on salmon was made with louver slat spacing reduced to 1 inch. At this time a rubber tube 16 inches in diameter and 17 feet long, with a metal transition attached to the upstream end (to correspond to the by-pass connection proposed for the final structure) was installed at the by-pass discharge. As the tube was too small to pass the flow moving through the 6-inch by-pass, the by-pass was reduced to a width of 4 inches. Successful use of the 4-inch by-pass by salmon and striped bass indicates that this width is satisfactory. Earlier studies with a by-pass 2.5 inches wide also gave completely satisfactory results. Table 3 shows the results of these tests.

TABLE 3.—*Efficiency of louvers for by-passing salmon*[1]. *Slats spaced at 1 inch; line of louvers at 16° and 4-inch by-pass connected to 16-inch by-pass tube.*

Test Number	Number of fish through louvers	Number of fish through bypass	Percent efficiency	Average water velocity (feet per second)
1	1	87	99	3.1
2	3	147	98	4.5
3	4	103	96	3.5
4	2	37	95	3.2
5	4	92	96	3.3
6	2	71	97	3.3
7	5	163	97	2.9
8	6	97	94	2.4
9	11	356	97	3.0
10	7	293	98	3.6
11	1	57	98	2.6
12	3	132	98	2.9
13	0	159	100	3.2
Totals	49	1,794		
Average			97.3	

[1]Salmon migrants of 73.6 millimeters mean standard length.

TABLE 4.—*Efficiency of louvers for by-passing salmon. Slats spaced at 1 inch. louver line at 16° and with a 4-inch by-pass connected to a 20-foot net.*

Test Number	Number of fish through louvers	Number of fish through bypass	Percent efficiency	Average water velocity (feet per second)
1	52	1,260	96	2.9
2	48	728	94	2.4
3	11	58	84	1.7
4	22	397	94	3.0
5	1	72	99	1.4
6	2	121	99	2.1
7	4	71	95	2.3
8	9	146	94	3.5
9	15	127	90	2.2
10	29	206	88	2.6
11	6	183	97	3.5
Totals	189	3,315		
Average			93	

[1]Salmon migrants, 73.2 millimeters in mean standard length.

Water velocities at the entrance of the live-tank when the rubber tube was used were as high as 5.5 feet per second and fish within the tank became exhausted from struggling against the turbulent flow. To eliminate the turbulence, the rubber tube was replaced by a tubular net attached at its forward end to the by-pass and at its back to the live-trap. The by-pass flow then passed through the sides of the net and its velocity was dissipated before reaching the live-trap. The test results shown in Table 4 confirm those shown in Table 3.

Water velocities indicated in the tests reflect tidal influence and number of pumps in operation. Velocity determinations were made in Bay No. 1 during each louver test. Test flume studies on salmon showed that these fish could be guided at flow rates as low as 0.2 feet per second. At Tracy such minimum velocities will seldom occur. Also because the number of fish moving into a fish screen area are proportionate to the amount of water carrying them, it is expected that few fish will be encountered at Tracy during periods of reduced pumping.

Striped Bass tests

On June 14, 1955 striped bass were noted. Louver efficiency tests began immediately and results are indicated in Tables 5, 6, 7 and 8. Table 5 shows that striped bass of minimum length of 8 millimeters can be guided as safetly into the by-pass as could the larger bass. In the clear water of the test flume, striped bass as short as 8 to 12 millimeters displayed the same favorable positioning reaction to louvers as the larger striped bass.

Table 5.—*Efficiency of louvers for by-passing striped bass*[1]. *Slats with 1-inch spacing; by-pass 4 inches wide and line of louvers at 16°. June 14-29, 1955*

Test Number	Number of fish through louvers	Number of fish through bypass	Percent efficiency	Average water velocity (feet per second)
1	82	793	91	2.9
2	142	1,193	90	3.0
3	253	1,792	88	2.8
4	382	3,649	91	2.5
5	223	1,729	89	3.1
6	120	1,248	91	2.7
7	173	1,706	91	3.2
Totals	1,375	12,110		
Average			90	

[1]Striped bass migrants of a mean standard length of 16.6 millimeters (0.66 inch).

Table 6 shows that striped bass which passed downstream and moved into the safety of the by-pass collector during the period of July 9 through 18 had a mean standard length of only 20.8 millimeters or 0.84 of an

TABLE 6.—*Efficiency of louvers for by-passing striped bass*[1]. *Slats with 2-inch spacing; by-pass 4 inches wide and louver line at 16°. July 9-18, 1955*

Test Number	Number of fish through louvers	Number of fish through bypass	Percent efficiency	Average water velocity (feet per second)
1	68	726	91.4	3.2
2	122	1,280	91.3	2.9
3	149	1,118	88.2	2.5
4	100	1,040	91.2	3.3
5	63	793	92.6	3.1
6	89	943	91.4	3.0
7	84	1,169	93.3	2.8
8	62	954	93.9	2.2
9	65	780	91.7	3.2
10	75	889	92.2	2.9
11	17	933	98.2	3.0
Totals	928	11,436		
Average			92.5	2.3

[1]Striped bass migrants of mean standard length of 20.8 millimeters.

TABLE 7.—*Efficiency of louvers for by-passing striped bass*[1]. *Slats spaced alternately at 1 and 2 inches and line of louvers at 16°.*

Test Period	Number of tests	Number of fish through louvers	Number of fish through bypass	Percent efficiency	Average water velocity (feet per second)
Day.....	13	351	3,253	90.3	1.7
Night.....	17	377	8,439	95.7	1.9
Totals.....	30	728	11,692		
Average.....				94.1	1.8

[1]Striped bass migrants of mean standard length of 34.3 millimeters.

inch. Collection efficiency was 92.5 percent. That by-passing efficiencies increase with increasing size of fish is indicated by the striped bass tests in Bay No. 1 in 1954. Striped bass with a mean standard length of only 34.3 millimeters were by-passed with a 94.1 per cent efficiency (Table 7.). Success in guiding fish into the by-pass in the final structure is expected to be even higher because of improved structural design and better approach flows.

As planned, the final structure will contain 4 by-passes which can divert a total maximum flow of 120 cubic feet per second. This volume will be reduced 90 percent prior to discharge into the holding ponds by a secondary louver system. A model of this system was tested in the flume and results with striped bass are shown in Table 8.

TABLE 8.—*Efficiency of a double set of louvers for by-passing striped bass*[1]. *Slats spaced at 2 inches; louver line at 16° and average approach velocity of 2.6 feet per second*

Test number	Number of fish through louvers	Number of fish through bypass	Percent efficiency
1	3	161	98.2
2	2	198	99.0
3	3	144	98.0
4	3	220	98.7
5	5	332	98.5
6	1	137	99.2
7	0	206	100.0
8	4	430	99.1
Totals	21	1,828	
Average			99.0

[1]Striped bass of mean standard length of 22.2 millimeters.

TROUT TESTS

Few trout entered the screen area and there has been little study of their reaction to louvers. Investigations made are related to by-pass widths and night versus day operation.

Wild steelhead trout 37 to 44 millimeters long were supplied by the State of California for several experiments. In the first studies, it was noted that the majority of loss through the louvers was near the by-pass. Trout are more excitable than salmon or striped bass and it was thought tha greater efficiency might be had by increasing the by-pass width from 6 inches to 18 inches. This was done with improved results. Further study, however, is necessary on this method for improving louver operation for trout.

The few tests completed with trout indicate they react more favorably to louvers in the daytime than at night. Better visibility is perhaps a factor.

Use of a high velocity approach current is suggested to bring trout safely along a set of louvers. This might force the fish to direct more attention toward maintaining their position relative to the louvers and prevent their meandering.

Debris in Louvers

Debris carried by the water toward the pumping plant was stopped by trash racks. This debris included floating and submerged logs, pond weeds, branches, and miscellaneous trash. Leaves were seldom found on the structure; a situation not encounted at most diversions.

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THE OTTER TRAWL AS A FISH SAMPLING DEVICE IN WESTERN LAKE ERIE[1]

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ABSTACT

Periodic fish collections were made in western Lake Erie with a thirty-foot otter trawl from 1948 through 1953. Prior to 1952, the number of silver chubs, *Hybopsis storeriana,* per collection were recorded for some of the trips. Biweekly trawls, usually consisting of four one-acre hauls, were made during 1952 and 1953. Records of the numbers of silver chubs per haul were kept. When hauls made during the spring migration period were excluded, a mean of 18.2 adults per haul was obtained with a standard deviation of 4.7. The results were sufficiently consistent to be used as a basis for further population comparisons.

A total of 33 fish collections consisting of 90.5 individual hauls of 12 minutes each were made with a thirty-foot otter trawl in the vicinity of the island region of western Lake Erie. Seven of these collections were made between 1948 and 1951. The remaining collections were made biweekly during the period from September, 1952, through September, 1953. Each full 12-minute haul covered an area of approximately one acre.

Records of the numbers of silver chubs, *Hybopsis storeriana,* were kept per collection. The average number of adults per haul was 21.0 with a standard deviation of 15.9. After the exclusion of two collections which deviated greatly from the mean, an average of 18.7 adults was obtained, with a standard deviation of 5.7.

Justification for the exclusion of these two collections was based on the findings of a shoreward migration of the silver chubs during April and May (Kinney, 1954). A collection of three hauls made in the open lake during this spring period netted six silver chubs while three hauls along the shore netted 293 specimens. The same areas were trawled again in June and an average of 18.8 adults were taken per haul.

During 1952-1953 period, records of the numbers of adult silver chubs per haul for 56.5 hauls were kept. A mean of 19.6 individuals per haul was obtained, with a standard deviation of 6.7 (Figure 1). When the four larger

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[1]A portion of a dissertation submitted to the Graduate Faculty of the Ohio State University in partial fulfillment of the requirements for the degree of Doctor of Philosophy, June, 1954.

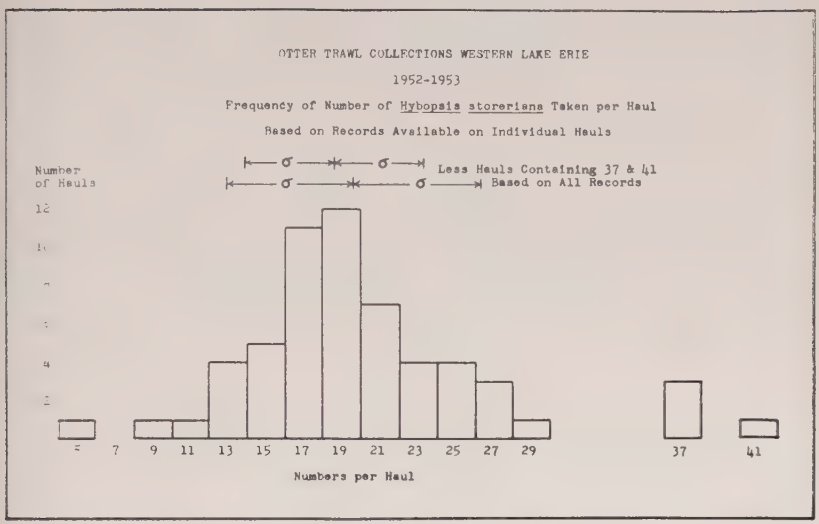

FIGURE 1.—Frequency of the number of silver chubs taken per haul based on individual hauls.

hauls, which were made along the shore during the spring, are excluded, a mean of 18.2 adults per haul with a standard deviation of 4.7 was obtained.

If all hauls are considered, the departure from Poisson distribution is highly significant. If the hauls from the two largest and three smallest collections are excluded, a chi-square of 12.24 with eight degrees of freedom is obtained. Although this chi-square is not significant, it is rather high and indicates that the silver chubs in western Lake Erie are scattered in loose schools.

The data gathered during the 1952-1953 period were sufficiently consistent to be used as a basis for future population comparisons.

The possibility of using the otter trawl to make comparative population estimates of other species shows promise. On the basis of the trawling collections made during the period from 1948 through 1953, it is believed that with the type of trawl used (Daiber, 1950, Kinney, 1954) comparative estimates could be determined for the following species:

Adults	Young
Hybopsis storeriana	*Aplodinotus grunniens*
Notropis hudsonius	*Morone chrysops*
Percopsis omiscomaycus	*Perca flavescens*
	Percopsis omiscomaycu

These species were taken by the trawl in considerable numbers throughout the year. Through the use of echo sounders and any-depth trawls, this species list could be enlarged.

Acknowledgments

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EXPERIMENTAL INDUCTION OF BLUE-SAC DISEASE

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ABSTRACT

Blue-sac disease, an abnormal condition of sac fry, has been recognized for nearly 90 years. At least 23 postulated causes have been advanced, but reports of consistently reproducible results have not been found in literature. Methods whereby blue-sac disease was induced at will are described. Closed-system incubation, whereby metabolic wastes accumulated, resulted in incidences of blue-sac disease roughly proportional to the period of holding and to ammonia concentrations which developed. Blue-sac disease was also induced by adding synthetic nitrogen compounds to water used for incubating eggs and fry.

INTRODUCTION

The following statements, according to Stone (1872) are axiomatic in fish disease research.

"1. No trout dies without a cause
2. The causes of death are discoverable
3. They can, in most instances, be removed."

Much progress has been made since Stone wrote his lucid axioms, but there are still many fish diseases about which little is known and for which controls have not as yet been found. Blue-sac disease is one of these. It has been recognized for nearly 90 years, but relatively little has been known of its nature and cause; nothing known about its treatment or prevention.

NATURE OF BLUE SAC DISEASE

Blue-sac disease is an abnormal condition that affects the egg and sac fry stages, typically of trout and salmon, but also of other freshwater fishes whose young emerge with a relatively large yolk sac. Affected individuals have an accumulation of fluid around the yolk sac. The fluid usually appears to have a blue color. Though the volume of fluid is small at first it often develops to the extent that the yolk is completely surrounded. It may also invade the pericardium and lymphatic spaces. Blue-sac fry are generally retarded and lethargic, and their yolks are usually more opaque than those of normal fry. Various degrees of white spotting may also be present. Small or diffuse hemorrhages in the head and body are common in blue-sac fry. The yolk sac blood vessels are frequently flaccid and almost colorless; distal portions often appear to be missing.

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Exophthalmus (popeye) is often present, and in advanced cases there is a paralysis-like condition that is probably the result of turgor. Heart rate and respiration of affected fry are quite generally reduced. Histological examination usually reveals hepatic and renal blockage and severe cardiac pathology (Schereschewsky, 1935; Dieterich, 1938).

The disease often causes the loss of entire lots of trout and salmon fry. Plehn (1924) and Schäperclaus (1954) state that it is one of the most common diseases of sac fry of hatchery-raised salmonids. Hofer, the pioneer of fish pathology, recognized the blue-sac condition as the most serious disease of these young fishes (Hofer, 1896).

The literature of fish pathology contains many accounts in which blue-sac disease is mentioned as a secondary item or associated influence, but only 7 references reporting research on this disease (Fiebiger, 1903; von Betegh, 1912; Guberlet, 1931; Atkinson, 1932; Schereschewsky, 1935; Dieterich, 1938; and Wolf, 1954). At least 23 causes have been postulated for blue-sac disease, but none has been consistently demonstrated.

In general, the cause of a disease must be known before it can be rationally controlled. The purposes of this paper are to present the methods whereby blue-sac disease was repeatedly induced, to indicate the nature of the cause and to resolve the apparent conflicts that exist in literature.

Prelmininary investigations by the writer demonstrated that the blue-sac condition is apparently not an infectious disease but is the result of a factor or factors present in closed-system incubation. When eggs were incubated in vessels to which only air was admitted, blue-sac disease resulted. The incidence was usually greatest among the fry which hatched from eggs which had been held the longest. This indicated possibilities of chemical addition or depletion. Tests made of the water during extended closed-system incubation showed that oxygen values were usually about 9 p.p.m.; carbon dioxide was about 2 to 3 p.p.m.; and pH was about 8. According to Ellis (1948), these values are within the normal range of tolerance for freshwater fishes. Ammonia levels were unusually high; they often exceeded 20 p.p.m. Ammonia is one of the principal metabolic waste products of freshwater teleosts (Prosser, 1950), and it is toxic in relatively small concentrations (Ellis *op. cit.)*. For these reasons the study proceeded along lines which would determine whether this agent caused blue-sac disease.

Experiments on Induction of Blue-Sac Disease

Three experiments were set up to test the hypothesis that ammonia and related compounds cause blue-sac disease.

Experiment No. 1. Closed-system Incubation

Eggs from a single rainbow trout *(Salmo gairdneri)* were used in this experiment. Twenty viable eggs, 8 days old, were placed in each of three 500 milliliter flasks to obtain a replicate series. Each flask contained a half-liter of water which remained unchanged throughout the

experiment except for samples which were withdrawn for chemical analysis. The flasks were aerated continuously but were otherwise closed systems. At intervals of 4 days three additonal closed-system series were initiated thus, in all, 4 such series of closed-system incubation flasks were started before the eggs began to hatch.

If metabolic wastes are the cause of blue-sac disease, their effect should be minimized or inhibited by removal of them as soon as they were released into the water. Flasks of another closed-system series were therefore fitted with venturi pumps which circulated the water over a bed of activated charcoal; this effected circulation, purification and aeration. Eight-day-old eggs were also used for this series.

Two series of controls were used. In one series eggs were placed in floating plastic baskets which were kept in the trough along with the source lot of eggs. In a second series of controls eggs were placed in aerated flasks to which water was admitted at a rate which gave a change of water every 2½ minutes. Temperature of the water in which all eggs were incubated was 13°C. For ammonia analysis a 5 milliliter water sample was removed every other day from each flask and from the trough containing the baskets. Five milliliters of fresh water were then added to the flasks to maintain a constant volume. Ammonia determinations were made by nesslerization according to the method of Symons (1947), and ammonia determinations are expressed as parts per million of ammonia nitrogen.

A single pipette was used to draw the water samples for chemical analysis. The pipette was not disinfected between the different series, and the order of selection was changed each time. This systematic violation of principles of sanitation was intended to show that infection was not involved in blue-sac disease.

Blue-sac disease was diagnosed by examining each fry every day. Fry were deemed to have blue-sac disease when the volume of their yolk sac fluid equalled that of a preserved standard specimen. The stan-

TABLE 1.—*Average percentage hatch, mortality and blue-sac disease among portions of one lot of eggs incubated under different conditions.*

Treatment	Average percentage hatch	Final percentage mortality	Average peak percentage of fry with blue-sac disease
Lot control (in baskets) at H-17[1]	91.6	13.3	31.0
Experimental control (air and water) at H-17	95.0	28.3	45.2
Closed system w/charcoal at H-17	93.3	100	42.7
Closed system at H-17	none	100	no hatch
Closed system at H-13	86.6	100	90.4
Closed system at H-9	25.0	100	96.6
Closed system at H-5	61.7	100	66.1

[1]H indicates date of hatching; the number which follows indicates the number of days prior to hatching that the series was started.

dard specimen was comparable to Stage I of Dieterich *(op. cit.)*.

Blue-sac disease was induced in a greater percentage of the fry in the closed-system flasks than in the fry in the controls and in the charcoal filter series (Fig. 1 and Table 1). Eggs which had been held the longest in the closed-system flasks died before hatching. There was a hatch of over 90 percent of the eggs in the charcoal filter series which had

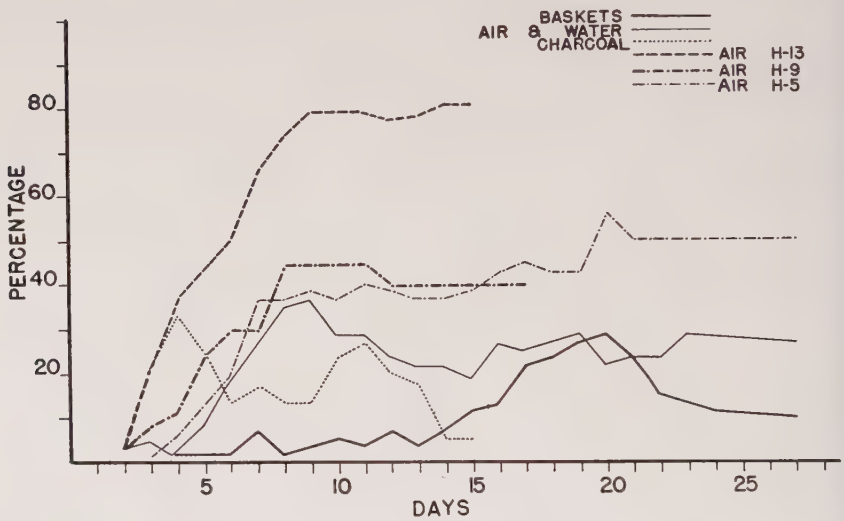

FIGURE 1.—Average daily incidence of blue-sac disease among fry incubated in closed system series (Air; H-13, H-9, H-5) as compared to the incidence among fry in control series (baskets, air and water) and in a closed-system series containing activated charcoal.

been started at the same time. Before mortality terminated one series (closed-system H-9), the curves of blue-sac disease of fry in the closed-system series showed a graded incidence; the highest percentage of fish with the disease occurred among the fry of the oldest series, and the lowest percentage in the fry of the youngest series. The highest incidence of blue-sac disease also occurred among the fry of those flasks which had greatest concentrations of ammonia (Fig. 2). Relatively high percentages of blue-sac disease occurred among the fry of both series of controls and in the charcoal series fry, but the percentages were much lower than those for the fry in the closed-system series which was in operation for the shortest time. This is emphasized, because the youngest closed-system series was started only 5 days before hatching and consequently had 12 fewer days for exposure to and accumulation of metabolic wastes.

The peak occurrence of blue-sac disease in the charcoal series occurred immediately after hatching. Ammonia concentrations rose abruptly during hatching, and in spite of almost daily change of the charcoal, the concentration approached 1 p.p.m. and was slow to be reduced. Some blue-sac disease could have resulted from this exposure to a low level of ammonia.

Previous experiments showed that some blue-sac disease usually occurred in the control fry. In Experiment No. 1 the percentage of diseased fish in the controls, as shown in Table 1, was higher than usual. The difference between the average percentage of blue-sac fry of the two series of controls is difficult to explain. The water manifold which supplied the experimental control flasks was the site of accumulations of gases which escaped from solution. These accumulations temporarily blocked the flow of water especially at night when the flasks went unchecked for hours. Interrupted flow may therefore account for the higher incidence in the control flasks than in the basket controls. In the light of results obtained from Experiment No. 3 it is considered likely that water movement past the eggs in

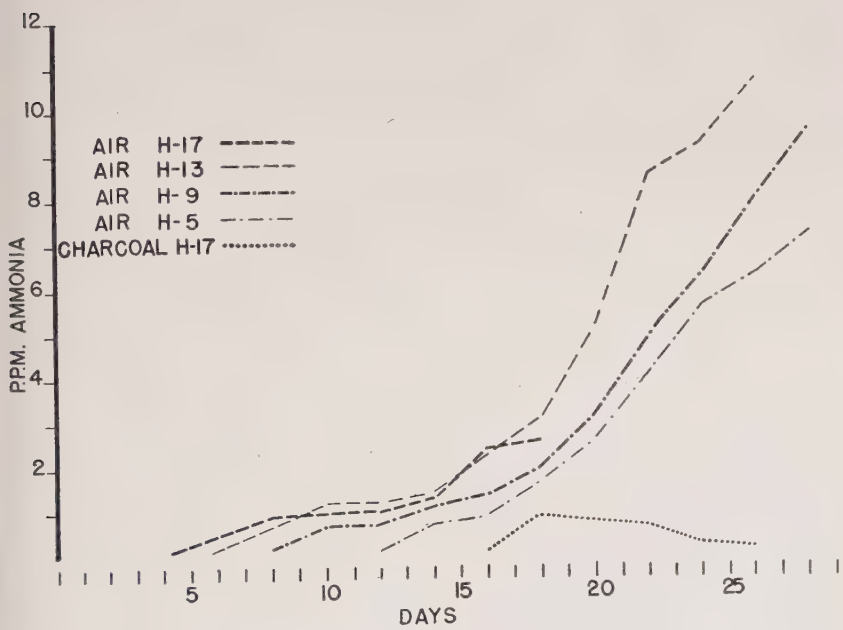

FIGURE 2.—Daily ammonia levels of water from closed-system vessels used in experimental induction of blue-sac disease. Ammonia is expressed as p.p.m. nitrogen. H indicates the date of hatching; the number which follows indicates the number of days prior to hatching that the series was started. Only trace quantities of ammonia were found in the water from both series of controls, therefore, the curves for these series have been omitted.

both the baskets and in the control flasks was not always adequate and that a partial or temporary stagnation occurred.

In spite of regular cross-transfer of water between the series, blue-sac disease showed no evidence of being infectious or of spreading. Oxygen determinations were made on several closed system flasks at termination of the experiment. The values ranged from 6.8 to 8.6 p.p.m. Values for pH ranged from 7.8 to 8.2.

Experiment No. 2. Addition of Ammonium Hydroxide to Incubation Water

If an accumulation of nitrogenous metabolic wastes caused blue-sac disease, it should be possible to induce the disease by adding synthetic forms of these compounds to water used for incubation. Levels of ammonia reported to be toxic had been found in the preliminary work, and further evidence of the harmful nature of this compound was obtained from Experiment No. 1. Ammonium hydroxide was chosen as the synthetic nitrogen compound for this experiment.

Twenty eggs of brook trout *(Salvelinus fontinalis)* hatchery stock were placed in each of two 500 milliliter Erlenmeyer flasks 9 days before they were due to hatch. Water at about 13°C. was supplied from reservoirs to each flask at a rate of about 1 liter per hour. One flask, the control, received hatchery water. Ammonium hydroxide was added to water supplying the other flask. A concentration of 1.5 p.p.m. ammonium hydroxide was used until the day of hatching. On the following day the concentration was increased to 2 p.p.m. and this level maintained for 3 days. Concentration was then increased gradually and on the 18th day after initiation of the experiment a concentration of 6 p.p.m. ammonium hydroxide was used. This concentration was maintained until termination of the experiment on the 30th day.

Fry in the control flasks and in the flasks which received water to which ammonium hydroxide had been added both developed a maximum incidence of 85-percent blue-sac disease. Average incidence during the last 10 days of the trial was the same for fry of both the experimental and control series. High mortalities in both series forced termination of the experiment, but at that time the disease incidence in the control lot was declining more rapidly than the lot receiving water with added ammonium hydroxide. A 5-percent sample of eggs from the same female trout, which eggs had been hatched in another trough under normal hatchery practice, showed about 9-percent blue-sac disease. Blue-sac disease was induced under the conditions of the experiment, but the effect of addition of ammonium hydroxide was not demonstrated. Partial stagnation may have occurred which could have permitted ammonia in the control flasks to increase beyond the concentration that was added, and thus both groups subjected to conditions favorable for development of a high level of blue-sac disease. The concentration which had been added to the experi-

mental flasks was considerably below the level that accumulated during closed system incubation with a similar number of eggs.

Experiment No. 3. Addition of Ammonium Hydroxide And Urea to Incubation Water

This experiment was a modification of Experiment No. 2. Eyed brook trout eggs from several redds were pooled, and 30 eggs were placed in each vessel. Two 200 milliliter straight-walled glass vessels were used instead of flasks. The possibility of hydraulic isolation was eliminated by keeping the eggs in plastic-screen baskets which were snugly fitted a few centimeters above the bottom of the glass vessel. A similar basket capped the glass vessel and permitted overflow without the loss of fry. Siphons of 1 millimeter intake and outlet diameter carried about 100 milliliters of water per minute from elevated reservoirs to each of the 2 glass vessels.

Ammonium hydroxide and urea were added to one reservoir each time it was filled. On the first day ammonium hydroxide and urea were added at both times the reservoir was filled to obtain a concentration of 2 p.p.m. for both substances. The concentration was increased to 4 p.p.m. on the 2nd day, to 8 p.p.m. on the 3rd day and to 10 p.p.m. on the 4th, 5th and 6th days. On the 7th day, a concentration of 12 p.p.m. was used, and this concentration was maintained until termination on the 23rd day.

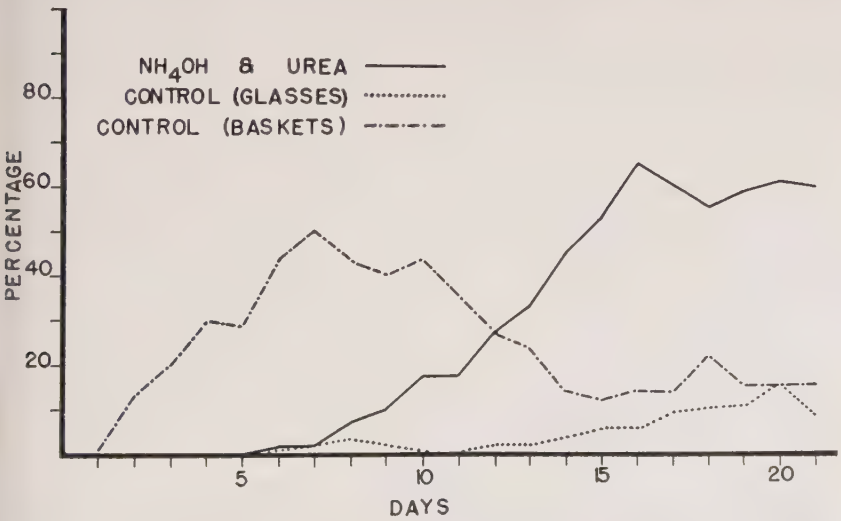

Figure 3.—Daily incidence of blue-sac disease among fry incubated in water to which ammonium compounds were added as compared to the disease incidence among fry incubated in water to which ammonium compounds were not added.

Two sets of controls were employed. The first consisted of 2 glass vessels which received hatchery water. The second consisted of 2 plastic-mesh baskets floated in the reservoir which supplied water to the control vessels. Water temperature was about 13°C. throughout the experiment.

An average of 65-percent blue-sac disease developed among fry in the series which had been treated with ammonium hydroxide and urea. Fry of the control vessels which had been treated the same except for

TABLE 2.—*Experimental induction of blue-sac disease in fry by the addition of ammonium hydroxide and urea to the incubation water.*

Treatment	Percentage hatched	Percentage mortality	Maximum percentage blue-sac disease
NH_4OH and urea	100	93.4	63.4
NH_4OH and urea	100	80.0	66.6
Control (glasses)	100	3.4	13.3
Control (glasses)	100	6.7	16.6
Control (baskets)	100	0.0	46.6
Control (baskets)	83.4	30.0	53.4

the addition of the chemicals had an average of only 15-percent blue-sac disease (Fig. 3 and Table 2), but fry in the series of baskets floating on the surface of the reservoir that supplied the control vessels had an incidence of 50-percent blue-sac disease. This is regarded as almost conclusive evidence against an infectious nature for blue-sac disease. Hydraulic isolation or stagnation appeared to be the explanation. This was verified by dropping crystals of malachite green into the reservoir. The resulting cloud of dye remained nearly intact for hours. Stratification appeared to be present, because streams of dye were seen to move to the siphon intakes along the bottom. If stagnation under such a situation occurs, it was likely to be disrupted when the fry hatch. Their movements would agitate the water, and this would probably alleviate the situation. This supposition was supported by the fact that although the incidence of blue-sac disease was high, the mortality was relatively low. Stagnation probably existed for only a short time before being alleviated by the fry. Further evidence was found in the fact that fry in the control baskets reached their peak incidence of blue-sac disease in 7 days, but the disease incidence among fry in the ammonium hydroxide and urea series continued to increase for 11 days and then declined only slowly (Fig. 3).

The percentage of hatch was uniformly high in the experimental series and in the controls. There was little spread between the results from each pair (Table 2).

An average total mortality of 86.7 percent occurred among fry of the series which had been treated with ammonium hydroxide and urea. Fry

in the series which had been held in floating baskets had an average total mortality of 15 percent.

An Explanation of Hatchery Occurences of Blue-Sac Disease

The apparent cause of blue-sac disease under experimental conditions remains to be demonstrated as the cause of the disease in the hatchery and in the wild, but there is reason to believe that the cause is the same.

Experimental evidence indicates that blue-sac disease occurs as as result of some form of stagnation, partial, temporary or local, which allows metabolic wastes to accumulate. The accumulation is probably restricted in time and/or space, because more severe conditions would undoubtedly result in death.

The efficiency of water flow used for fish culture has, until recently, been given little more than sporadic, informal, philosophical treatment. Burrows and Chenoweth (1955) recently made a study of the hydraulic characteristics of fish-rearing ponds. They found dead areas present in 3 common types of ponds studied. This writer considers it likely that similar areas of poor or inadequate water flow occur in hatching facilities.

Small-mesh screen used on trays in the Clark-Williams method of incubation often collect huge flat air bubbles between the trays. Overcrowding of eggs and fry was occasionally encountered in all methods of incubation. Mats of debris and/or fungus occasionally blanket some eggs. Water tends to go around such impediments, and this can give rise to localized or temporary stagnation.

Partial or localized stagnation may be the reason why an outbreak of blue-sac disease seldom involves the total lot of fry and why it can occur in trays at the head of the trough without involving lower containers. The common occurrence of severe blue-sac disease in fry from eggs which had been in transit for long periods of time may be a result of the same basic cause. Eggs in transit continue to develop, and waste products are excreted. If such eggs are poorly iced or too densely packed, the volume of melt-water that passes them may not be adequate to remove metabolic wastes. Consequently, even though they are moist, they may be literally surrounded by a film of their own pollution.

Ammonia is probably involved, but other nitrogenous products are not excluded as possibly contributing their influence. If circumstances permit, it is planned for the future to determine quantitative values of time and concentration for ammonia and other products of metabolism excreted by the developing eggs and fry.

Acknowledgment

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BIOLOGY AND MANAGEMENT OF LAKE TROUT IN GREEN LAKE, WISCONSIN

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ABSTRACT

Information on spawning, feeding habits and on growth and condition of planted lake trout in Green Lake, Wisconsin, is presented. Failure of natural reproduction of the planted trout of Great Lakes stock in this lake is attributed to lack of cover for the eggs on the spawning bar and subsequent predation by Necturus. An artificial spawning bed of angular fragments of rock deposited on the spawning bar in 60 to 100 feet of water appears to be providing the necessary egg protection. In this oligotrophic lake of 7,325 acres *Mysis* is the main food of immature trout shorter than 14 inches and ciscoes the principal food of adult trout longer than 27 inches. Length-weight relationship is of the usual pattern and coefficient of condition for the younger fish about the same as that reported for Great Lakes trout but is higher for the larger adult fish. Average egg production of 18 females, at least 12 years old, was 5,417 eggs in the fall of 1956. It is suggested that selection of an unfavorable deep-water spawning area in preference to more suitable areas in shallower water is inherent in the race of trout stocked here.

INTRODUCTION

From 1886 until 1944, lake trout, *Salvelinus namaycush* (Walbaum) were stocked in Green Lake, Green Lake County, Wisconsin. Plantings were then discontinued because of the inability of the angler to harvest many of these fish. Test nets set prior to 1944 indicated good populations of lake trout. In 1952, eight years after the last stocking, an angling lure[1] was found that took lake trout readily, and in three months, over 700 adult lake trout were taken which averaged 33.2 inches in total length, and 15.9 pounds in weight. Some of the fish were as large as 44.0 inches and 34.25 pounds, but none was taken under 25.5 inches and 5.75 pounds. From the generally large size of the trout taken, it appeared that natural reproduction in the lake was extremely limited or non-existant. Because of this condition, lake trout reproduction in Green Lake was investigated and attempts made to improve facilities for spawning.

DESCRIPTION OF GREEN LAKE

Green Lake, a typical oligotrophic lake, is Wisconsin's deepest and fourth largest natural inland body of water. It has a maximum depth of 221 feet, and a surface area of 7,325 acres. The lake is 7.7 miles long, about

[1]An elongate, flexible, chrome-plated metal lure used in conjunction with a set of flashing spinner blades trolled behind a rowed boat, normally in 50 to 90 feet of water.

three miles wide and has a shoreline of 27.3 miles. Juday (1914) stated that the lake is located in a pre-glacial valley underlain by sandstone, flanked by highlands of hard limestone. In Pleistocene time the valley lay in the direct path of glacial ice which scoured and excavated the lake basin in weak sandstone bedrock.

The shoreline varies from steeply sloping sandstone bluffs to shallow, white sand beaches. At some locations, the lake deepens precipitously, deepening almost a foot for every foot travelled from shore, while in others the bottom slants very slowly into deep water.

Of the streams that drain into Green Lake, the largest is Silver Creek. White, Roy, Spring and Dakin Creeks are small, spring-fed streams. The outlet stream, the Puckyan River flows into the Fox River system, and eventually into Green Bay of Lake Michigan.

The major warm-water fish species in the lake are northern pike *(Esox lucius)*, yellow walleye *(Stizostedion v. vitreum)*, smallmouth bass *(Micropterus dolomieu)*, largemouth bass *(M. salmoides)*, white bass *(Morone chrysops)*, northern channel catfish *(Ictalurus lacustris)*, northern rock bass *(Amboplites rupestris)*, black crappie *(Pomoxis nigromaculatus)*, yellow perch *(Perca flavescens)*, and bluegill *(Lepomis macrochirus)*. The shallow-water cisco *(Coregonus artedii)* occurs in abundance in the deeper, colder waters of the lake. The most abundant minnow found in the lake is the lake emerald shiner *(Notropis atherinoides)* which is present in such large numbers that waters along the shoreline during spawning may appear clouded with them. Carp *(Cyprinus carpio)* inhabit the shallow lower stretches of several of the inlet streams, but seem to have little effect on the lake or its fishes.

Natural Reproduction of Lake Trout in Green Lake

Following the discovery that only large, mature lake trout were being taken by anglers, a study was initiated to determine whether or not naturally reproduced small trout were present in the lake. During the fall of 1952 and the winter of 1952-1953, 8,040 feet of gill net, ranging in stretch measure from 1¼ to 4 inches were set at depths of from 17 to 203 feet. Of 70 adult lake trout taken, none was smaller than 5.75 pounds, substantiating the supposition that natural reproduction was lacking or extremely limited.

During April, 1953, 20,000 fingerling fin-clipped lake trout were stocked in the lake. Almost immediately, anglers began to report taking these 6- to 9-inch fish. Netting with fine mesh nets during the winter of 1953-1954 yielded nine of the small fin-clipped trout. All lake trout stocked since that time, some 105,662 fish, have been marked with distinctive fin-clips to obtain age and growth data, and to serve as an additional source of information on the occurrence of naturally reproduced trout.

Location and Description of Spawning Grounds

During 1952, a single spawning ground was found in 60 to 100 feet of water on a location called the Sugarloaf Bar(Fig. 1). From the concentrations of mature lake trout here, 371 were taken in gill nets during three spawning seasons. Many of the fish were in a spent condition, attesting to the fact that spawning took place in the vicinity.

The literature discloses that lake trout spawn at a great variety of depths. Royce (1951) observed spawning in shallow water in Otsego Lake, New York, and reported that in Seneca Lake in the same state, trout are captured for stripping in 100 to 200 feet of water. Van Oosten (1944) reported that lake trout in the Great Lakes spawn in water as shallow as two or three feet, and as deep as 360 feet. Rawson and Elsey (1949) reported that lake trout spawn on rocky bottom in depths of seven to 25 feet in Pyramid Lake, Alberta, and Martin (1947) noted that the lake trout of Lake Louisa, Ontario spawned in waters ranging in depth from 8 inches to 5 feet, with the backs of spawning trout frequently breaking the surface.

Dredgings of the bottom deposits from the Sugarloaf Bar spawning area in Green Lake showed the bottom soils to range in texture from pure silt, hardpan blue clay, and marl to egg-sized gravel embedded in sand. Small areas of uptilted stratified limestone were found later by divers. These provided little or no protection from predation for lake

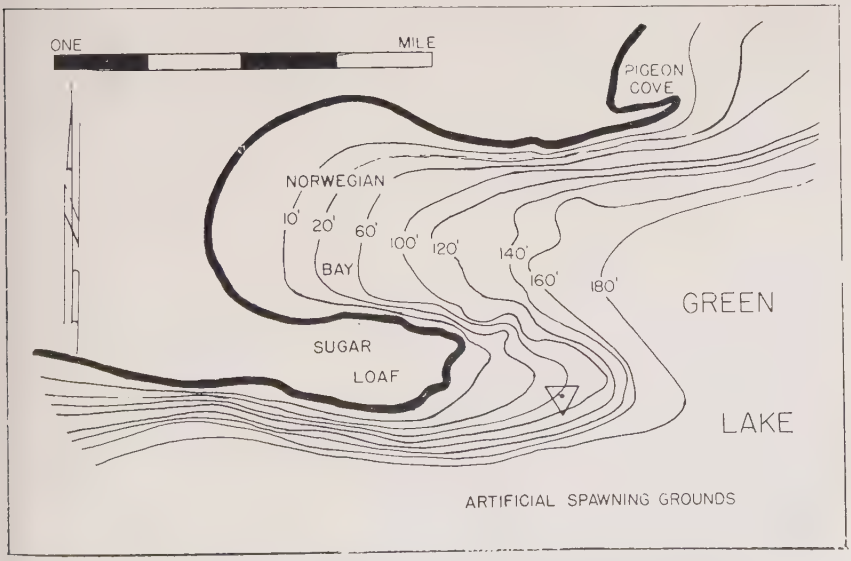

Figure 1.—Contour map of Sugarloaf Bar area, Green Lake Wisconsin. Dot inside triangle shows location of artificial spawning area.

trout eggs. The wide variety of soils used for lake trout spawning in Green Lake is in contrast with the limited variety of bottom soils reported as used by lake trout in other lakes. Royce (1951) observed that lake trout spawning areas in New York lakes are restricted to bottoms of clean gravel or rubble that are free of sand or mud. Van Oosten (1944) noted that spawning most commonly occurs on reefs in the Great Lakes where honey-comb rock of Silurian coral origin covers the bottom, or on hard clay bottom in deep water. Martin (1947) stated that the spawning area was of rubble bottom, with most of the stones varying in diameter from one to six inches with larger boulders interspersed. He also stated that sand was entirely absent from the area, as was mud, detritus and vegetation. It appears that since lake trout make no effort to bury their eggs, crevices or holes in the rock are necessary for protection of eggs and fry, particularly when egg predators are present, if successful natural reproduction is to be assured.

In Green Lake, lake trout spawned persistently in deep water, over a uniformly smooth and soft bottom which appeared to be unsuitable for the protection of eggs and fry. Why was this bar used for spawning, when extensive areas of wave-washed rubble were found at many places about the shoreline?

It is likely that all the adult spawning fish at Green Lake originated from plantings made before 1944 of fry and fingerlings obtained from hatcheries on Lake Michigan, particularly at Sturgeon Bay and Sheboygan, Wisconsin. These young trout were obtained from adults which were taken on the spawning grounds of southern Lake Michigan in 180 to 360 feet of water, over hard clay bottom. The 1944 planting was of fry, believed to have originated from Lake Superior adults. The possibility is suggested that strains or races of deep- and shallow-water spawning lake trout exist. Inherited tendencies in the progeny of the deep-water spawning fish from southern Lake Michigan may account for their persistence in using a deep-water, but unsuitable location in Green Lake.

Egg Predation as the Cause of Failure Of Natural Reproduction

In the fall of 1953, spawning boxes three feet square and eight inches deep were filled with a variety of materials including angular, eroded slabs of limestone, clinkers, granite chips, rough gravel and round rocks six to 10 inches in diameter. These boxes were set on the spawning bar to determine whether or not lake trout would use them for egg deposition. The boxes were lifted once a week during the spawning period (October 20 through November 15), but only a few lake trout eggs were found in one of the boxes.

When the spawning boxes were being lifted, several mud puppies *(Necturus maculosus)* were found among the rocks in the bottom of a box. Examination of the stomach contents revealed that the amphibians

had eaten lake trout eggs. Immediately, traps were set at many locations on the spawning ground, and in them, 150 mud puppies taken. Stomachs of more than 70 percent of these contained trout eggs. As many as 85 eggs were found in one stomach and many of these were freshly eaten. Microscopic examination of the eggs taken from the stomachs showed them to be fertilized and in stages of embryonic development as far as late gastrulation. During following years, 1954 and 1955, trapping of mud puppies was continued. During 1953 to 1955, lake trout eggs were not found in stomachs of mud puppies or yellow perch later than December 10. It is concluded that all eggs available to predators were eaten in less than a month after spawning.

To test the preference of the mud puppy for fish eggs, immature sucker eggs and dead minnows were placed in three traps. Stomach contents of the mud puppies taken in these traps showed that almost invariably fish eggs were preferred to minnows.

After it was established that the amphibians would readily eat lake trout and other fish eggs if available, traps were also set at eight other likely locations for lake trout spawning about the lake to determine if additional spawning grounds existed. None of the stomachs examined from locations other than those in the vicinity of the Sugarloaf Bar contained trout eggs. On this basis it was concluded that spawning is confined to Sugarloaf Bar.

Bishop (1926) noted that "the abundance of *Necturus* in lakes and streams and its habit of eating fish eggs marks it as an enemy of certain fishes." Milner (1874) referred to the report of a fisherman who took 2,000 of these amphibians in a sweep seine, and found the mud puppies so gorged with whitefish spawn that when they were thrown on shore, hundreds of eggs would fly out of their mouths. Pearse (1921) also stated that the mud puppy does great damage by eating the eggs of fish.

Predation therefore presents a reasonable possibility for the lack of naturally-reproduced lake trout in Green Lake; both because of lack of adequate natural cover for eggs and fry, and because of known feeding habits of the mud puppy.

Existence of bottom currents with resulting water aeration remained to be considered as a factor affecting lake trout reproduction. In the winter of 1954-55, a box completely screened with 1/8 inch galvanized hardware cloth was deposited on the spawning bar. The bottom of the box was covered with coarse gravel, and more than 200 eyed lake trout eggs placed on this bottom. When the box was lifted 39 days later, 211 fry and five dead eggs were found, demonstrating that suitable water conditions were present on the bar.

Establishment and Use of an Artificial Spawning Ground

After it had been determined that lake trout eggs could hatch naturally in Green Lake if egg predators were excluded, plans were made for the

FIGURE 2.—Underwater photograph of artificial spawning ground in 67 feet of water. Approximately four square feet of bottom shown. White spots on rocks are embedded materials.

establishment of an artificial spawning ground on the Sugarloaf Bar. With the help of funds obtained under a Federal Aid Dingell-Johnson appropriation and from the Green Lake County Board of Supervisors, 210 tons of angular, granite rock, 3 inches to 2 feet in diameter were obtained. The material was then hauled out on the ice during March, 1955, and 6,000 square feet of bottom were covered to a depth of two feet.

In December of 1955, about eight months after the rock was placed on the reef, underwater photographs were taken of the artificial spawning ground to determine if lake trout eggs could be seen. None were noted, but the pictures showed quite clearly that currents apparently kept the artificially deposited rock swept clean (Fig. 2).

During January and February of 1956, fine mesh gill nets and mud puppy traps were set directly on the artificial spawning ground. Stomach samples were taken from all fish and amphibians collected. Lake trout eggs in stages of development as advanced as faintly eyed were found in many stomachs of yellow perch and mud puppies. This indicated that lake trout had utilized the artificial spawning area and that protection provided by this area allowed lake trout eggs to at least reach an advanced stage of development.

In March of 1956, a pumping apparatus described by Eschmeyer (1955) was used to lift more than 100 lake trout eggs from between the rocks of the artificial spawning ground. Divers with self-contained underwater breathing apparatus (SCUBA) operated the funnel and hose at the bottom, and turned over the rocks to expose the eggs. One diver who covered the spawning ground as extensively as possible, reported that there were thousands of eggs scattered everywhere in the crevices between the rocks.

On May 12, 1956, divers again operated the suction device on the bottom at the artificial spawning ground. Although extremely rough weather prevented anchoring of the equipment barge, four newly hatched lake trout fry were brought to the surface. Because the peak of spawning usually occurs in the lake about November 7, the incubation period for lake trout fry is estimated to be 175 days in Green Lake.

TABLE 1.—*Mean weight, range in weight, and coefficient of condition at the various length increments for adult lake trout taken from Green Lake, Wisconsin 1952–1956.*

Total length in inches	Number of samples	Mean weight in pounds	Range in weight in pounds	Coefficient of condition
25.0-25.9	1	7.8	—	2.20
26.0-26.9	5	7.6	5.8-10.0	1.97
27.0-27.9	10	8.4	7.0-10.1	1.92
28.0-28.9	22	9.0	6.0-16.8	1.87
29.0-29.9	39	10.4	7.0-16.8	1.93
30.0-30.9	41	11.3	8.5-17.8	1.89
31.0-31.9	62	12.5	8.8-18.5	1.88
32.0-32.9	58	13.4	10.2-17.3	1.87
33.0-33.9	90	15.4	10.8-22.1	1.96
34.0-34.9	52	15.7	12.4-23.0	1.84
35.0-35.9	29	16.8	12.6-21.8	1.79
36.0-36.9	22	20.3	15.5-26.0	2.00
37.0-37.9	24	21.7	16.8-28.0	1.96
38.0-38.9	11	21.1	17.3-26.4	1.77
39.0-39.9	7	24.7	20.0-30.2	1.89
40.0-40.9	5	25.0	21.3-30.1	1.81
41.0-41.9	2	35.1	33.0-37.3	2.28
42.0-42.9	1	25.3		1.61
43.0-43.9	1	27.3		1.56
44.0-44.9	1	30.5		1.68
Totals.....	483			
Means.....		14.6		1.90

Biological Characteristics of Lake Trout of Green Lake

Because planting of lake trout in Green Lake was terminated in 1944, and natural reproduction was probably non-existent, all adult lake trout captured after 1952 probably originated from pre-1944 plants. Accordingly, the trout caught between 1952 and 1956 are considered to be at least 9 to 13 years old depending upon the year in which they were caught.

Length-Weight Relationship of Adult Trout

Table 1 shows the average weight, range in weight and coefficient of condition by one-inch increments for 478 adult lake trout caught between 1952 and 1956. The weight increments shown in Table 1 demonstrate a gradual increase for succeeding one-inch groups, with sharp increases in weight at the 36 and 39 inch increments. Coefficient of condition is quite constant. As compared to Great Lakes trout, the Green Lake trout were deeper bodied fish. Van Oosten and Eschmeyer (1956) found a lower coefficient of condition for Lake Michigan trout, particularly for the inch groups shown in Table 1. Examination of the average coefficient of condition for the same length increments shows that of Green Lake to be 1.90 as compared to 1.46 for the Great lakes.

Food Studies of Adult Lake Trout

During the 1953 fishing season, stomachs of 72 adult lake trout older than nine years and ranging from 27.0 to 43.5 inches in length were turned in by a cooperator on the lake. Qualitative analysis of the stomach contents show that the major food item was the cisco. Twenty four of the stomachs examined were empty, 24 contained ciscoes only; 1 contained two 1-inch sunfish and 4 ciscoes; 1 contained 1 lake emerald shiner and a cisco; 18 contained ciscoes and unidentified fish remains only. Therefore, 44 of 48 fish, or 91.7 percent of the trout with food in their stomachs contained ciscoes. Of 86 fish positively identified in the stomachs, 83 or 96.5 percent were ciscoes, 2 or 2.3 percent were sunfish, and one or 1.2 percent was a lake emerald shiner. Thirty-one fish, or 26.5 percent of all the fish found in the trout stomachs could not positively be identified, but almost all had the internal characteristics of the cisco. It is interesting to note that despite a large population of stunted yellow perch in the lake, no perch have been found in stomachs of adult trout in Green Lake.

This is in contrast to the report of Fry and Kennedy (1937) who noted that the lake trout of Lake Opeongo, Canada fed on whitefish and yellow perch. However, Van Oosten and Deason (1938), Clemens, Dymond and Bigelow (1924) and Dymond (1928) found the lake trout of Lake Michigan, Lake Nipigon, Canada, and Lake Ontario, respec-

tively, as in Green Lake, feeding almost exclusively on fish, principally ciscoes. It is of interest to compare the findings of Leonard and Leonard (1947) with the findings for Green Lake. In Birch Lake, Michigan, the stomachs of lake trout contained warm-water fish and insects only, despite the presence of a cisco population of harvestable size.

Age Growth of Fin-Clipped Immature Trout

In 1953, after the start of the investigation, and in each succeeding year to 1956, lake trout have been stocked in Green Lake, with each plant given a distinctive finclip. To obtain information relative to the growth of these fish, the aid of reliable cooperating fishermen was enlisted to measure lengths and record the finclip marks of trout caught by angling during the ice fishing seasons of 1954-55 and 1955-56. Records for more than 200 were obtained in this way. In addition, lengths and weights of 119 lake trout of known age were obtained during spawn taking in the fall of 1956.

Table 2 shows the mean weight, range in weight and coefficient of condition associated with one-inch increments for 119 known-age lake trout for which both length and weight were recorded. Rise in weight increases gradually with length until the lengths of 19 and 22 inches are recorded. The portion of the table devoted to the range in weight at each length interval shows that as with the older unmarked lake trout, there is variation in weight at any length for the fin-clipped trout.

Table 2.—*Mean weight, range in weight, and coefficient of condition at the various length increments for immature lake trout taken from Green Lake, Wisconsin, 1954–56*

Total length in inches	Number of samples	Mean weight in pounds	Range in weight in pounds	Coefficient of condition
6.0-6.9	4	0.07	0.06-0.09	1.05
7.0-7.9	8	0.10	0.06-0.11	1.14
8.0-8.9	3	0.16	0.13-0.19	1.15
9.0-9.9	3	0.24	0.17-0.28	1.34
10.0-10.9	3	0.29	0.24-0.32	1.27
11.0-11.9	9	0.43	0.38-0.56	1.19
12.0-12.9	10	0.57	0.44-0.69	1.33
13.0-13.9	11	0.60	0.50-0.75	1.17
14.0-14.9	14	0.76	0.63-0.88	1.19
15.0-15.9	12	1.05	0.81-1.25	1.27
16.0-16.9	11	1.32	1.07-1.50	1.31
17.0-17.9	8	1.68	1.44-2.06	1.47
18.0-18.9	9	1.86	1.50-2.50	1.36
19.0-19.9	6	2.31	2.07-2.75	1.43
20.0-20.9	4	2.31	2.00-2.56	1.24
21.0-21.9	3	2.50	2.00-3.00	1.17
22.0-22.9	1	3.75		1.56
Totals.....	119			
Means.....		1.00		1.26

The coefficient of condition for the lake trout of Green Lake under five years of age is low as compared to that for adults shown in Table 1. However, lake trout of Lake Michigan as reported by Van Oosten and Eschemeyer (1956) show a similar coefficient of condition for fish of the same length distribution as those shown on Table 2. Average K for Lake Michigan is 1.25 as compared to 1.26 for the Green Lake fish within the length range of 6.0 and 22.9 inches.

Food Studies of Fin-Clipped Immature Lake Trout

Stomach samples from 76 of the fin-clipped trout stocked since 1953 have been examined. Of 19 trout between 6.0 and 9.9 inches, six were empty, six contained only the shrimp, *Mysis oculata relicta,* three contained unidentified fish remains, one contained *Mysis* and fish remains, and one a lake emerald shiner. Of 22 trout between 10.0 and 13.9 inches, four contained *Mysis,* twelve were empty, two contained fish remains and four contained ciscoes. Of 28 lake trout between 14.0 and 17.9 inches, two contained *Mysis,* twelve were empty, six contained fish remains, and eight contained ciscoes. Only seven lake trout were examined in the 18.0 to 22.9 range. Four were empty, two contained ciscoes, and one contained one yellow perch and one cisco. In this lake, *Mysis* is a common food of the smaller trout, but the diet of the larger fish is principally ciscoes. In the 6.0- to 9.9-inch range, 6 of 13 stomachs of those in which food was found, contained *Mysis,* and 7 had fish remains. In the 10.0- to 13.9-inch range, 9 of the 22 stomachs with food in them contained *Mysis,* and 13 contained fish remains. Of 16 fish in the 14.0- to 17.9-inch range which contained food, the stomachs of only 2 contained *Mysis* and 14 contained fish. *Mysis* were not found in the stomachs of trout in the 18.0 to 22.9 inch range. Only one yellow perch was found in the trout stomachs checked.

Length-Weight Relationship of Adult and Young Trout

Figure 3 shows graphically length-weight relationship of Green Lake trout. It will be noted that there is considerable variation in weight for a given length in the Green Lake lake trout. No data are available for the length increments between 23.0 and 25.5 inches because lake trout were not stocked between 1944 and 1953. The trout recorded in the 22.0-inch group represent the maximum growth of 1953 plants, taken during 1956, and the 25.5-inch fish represents minimum growth of trout planted in 1944 or before, and which were taken in 1952.

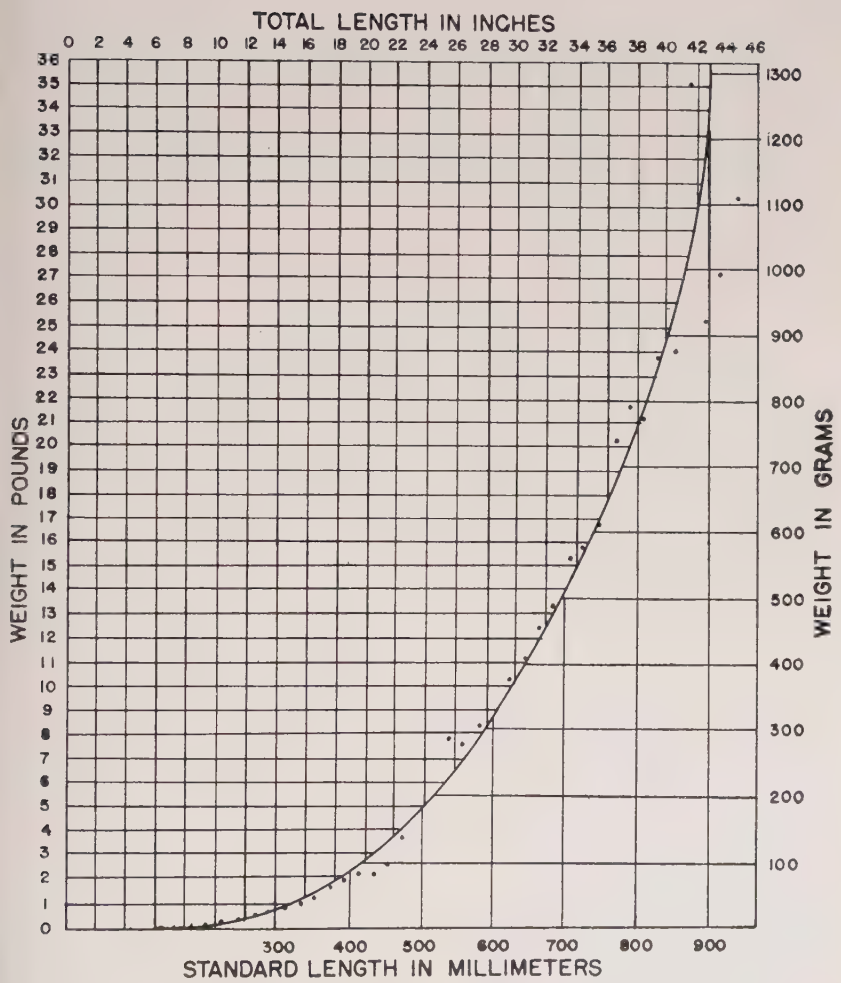

FIGURE 3.—Computed length-weight relationship for lake trout from Green Lake, Wisconsin, 1952–56.

Fecundity of Lake Trout

During the fall of 1956, nets were set in the vicinity of the artificial spawning ground in a effort to take lake trout eggs. A total of 18 ripe or partially ripe adult females were captured from which, 545 ounces of eggs were obtained. In size, the eggs ranged from 135 to 200 to the ounce and averaged 180 to the ounce. These numbers were obtained from an actual count of the number of eggs in a given volume, multiplied by the total volume. The total number of eggs estimated taken by this manner was 97,505, or an average of 5,417 eggs per female. Of 98 known-age, fin-clipped lake trout examined at the same time, none of which were older than five years, all were immature.

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SIZE AS A DETERMINANT OF GROWTH RATE IN RAINBOW TROUT *SALMO GAIRDNERI*

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Abstract

Growth rates of rainbow trout have been calculated and compared for 27 British Columbia lakes. The use of absolute age as a reference point is unsatisfactory in many cases where comparisons involve fish of the same age but of dissimilar sizes. Changes in metabolic efficiency may be primarily a function of size and not of age. An alternative method is suggested, which relates growth rate to size independent of age. Examples are offered of the use of size—specific average instantaneous growth rates.

Introduction

It is generally recognized that growth rate of an animal is a function of size, expressed in relation to either the size the animal has attained, or the difference between its size and an ultimate adult size (Brody 1945, Von Bertalanffy 1938). Genetic factors presumably set the basic parametre(s) of potential growth rate. Because size usually increases with age in a regular fashion, plotting size (length) at age n + 1 against size at age n can yield an estimate of ultimate size (Walford 1946). Growth of fish may not be so conveniently summarized mathematically. There may be no sharply defined "ultimate size." Moreover, many species of fish change their "ecological niche" as they grow larger, in effect perhaps revising the "ultimate size" to which their growth rate is related. Finally, many species of fish are relatively short lived. Where estimates of growth rate rely on scale reading for annuli, short-lived species provide few reference points for estimation of future growth. These facets of growth of rainbow trout *(Salmo gairdneri)* were the subject of the following studies which suggested a method for summarizing growth of fish which may be more suitable than analysis relating growth rate to age.

Rainbow trout (known locally as Kamloops trout) occur in lakes in most parts of British Columbia. The natural distribution is confined to lakes of relatively low altitude that have been accessible to the sea in recent geological time, but artificial culture has spread the species to lakes at high altitudes in the Province and to many watersheds that were otherwise barren of fish. Because the lakes of the Province show a great diversity in physical, chemical and biological characteristics (Northcote and Larkin, 1956) the rainbow trout populations show great variability in

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growth, affording an opportunity for comparative study. For example, in Jewel Lake near Grand Forks where trout of over 40 pounds have been recorded and in Kootenay Lake where trout of over 20 pounds are common, relatively high rates of growth are suggested, while at the other extreme many mountain lakes contain populations of mature fish none of which attain lengths of over 6 to 8 inches nor weights in excess of a few ounces.

Data for this study were derived from three sources; (1) lake survey studies conducted from 1949 to 1953, (2) special survey studies for evaluation of trout populations in 1954 and (3) research projects on certain lakes. All of these studies were supported by the British Columbia Game Department. The raw material is available for study in the files of the Game Department office at the University of British Columbia.

All calculations of growth rate have been based on reading of impressions of scales made on cellulose acetate strips by use of a jewellers' press. The usual precautions of collecting scales from a standard area on the fish were observed (in this case the area between the insertion of the dorsal fin and the lateral line). For back calculation of size at previous ages, the simple method of direct proportion was used. This procedure seemed justified in view of the findings of Smith (1955) that the slope of the log-log regression coefficient for the relation between fork length and scale diameter for Kamloops trout was not significantly different from unity. Unless specifically mentioned, all measurement of growth was based on fish which had not spawned *i.e.* in which resorbtion of the scale margin did not vitiate back-calculation.

Differences in Growth Rate of Trout from Various Localities

Table 1 gives mean fork lengths attained by rainbow trout of various ages for 27 lakes in British Columbia, together with calculations of $\log_{10}$ instantaneous annual growth rates ($\log_{10}$ fork length at age n + 1 minus $\log_{10}$ fork length at age n) based on the mean lengths attained at various ages. The fork length attained by age IV varies from as low as 19.23 cm. for Lightning Lake to as high as 55.10 cm. for Peterhope Lake; a range reflecting at least a 25-fold difference in weight.

Other lakes in the group show growth rates intermediate between these extremes and except for size attained in the first year the mean fork lengths at each age for Peterhope and Lightning represent the highest and lowest respectively of the whole series (Tunkwa Lake fish at age II are very slightly larger than Peterhope fish). Despite these facts the instantaneous annual growth rates ("i") for each age interval are not highest and lowest for these two extremes of size attained. Three lakes have higher "i_{12}" than Peterhope,[1] eight have higher "i_{23}", and thirteen

[1]That is, higher instantaneous growth rate for age interval I to II.

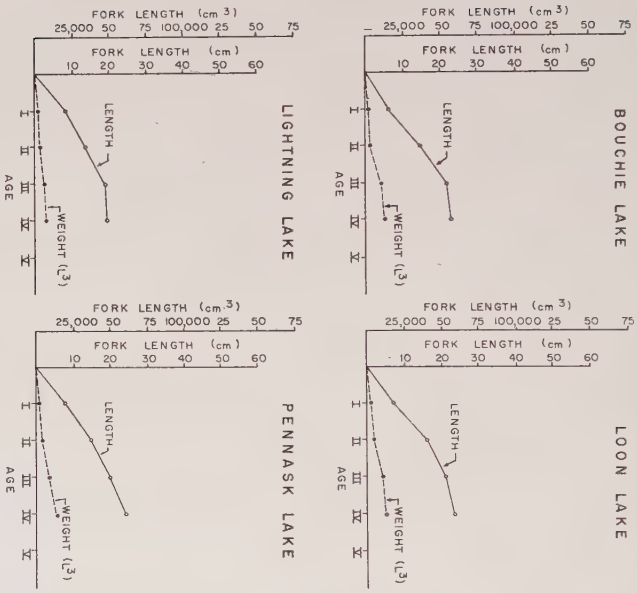
TABLE 1.—*Mean fork length in centimeters and instantaneous annual growth rates of rainbow trout at various ages for lakes in British Columbia. [Numbers in brackets give sample sizes. Instantaneous growth rate is* $\log_{10}$ *fork length in centimeters at age n + 1 minus* $\log_{10}$ *fork length in centimeters at age n]*

Locality	Age				Instantaneous annual growth rates		
	I	II	III	IV	i_{12}	i_{23}	i_{34}
Cluculz L.	5.31 (51)	14.83 (47)	27.51 (17)	27.68 (2)	.445	.269	.003
Tunkwa L.	7.90 (39)	31.75 (30)	37.95 (3)	—	.604	.077	—
Bouchie L.	5.97 (58)	15.11 (58)	22.20 (32)	22.81 (2)	.403	.165	.012
Lightning L.	8.06 (98)	13.64 (94)	18.25 (54)	19.23 (4)	.229	.127	.023
Loon L.	6.96 (82)	16.28 (78)	21.34 (50)	22.96 (2)	.369	.118	.032
Pinantan L.	6.00 (87)	14.22 (86)	24.00 (62)	28.12 (15)	.375	.227	.069
Hyas L.	6.50 (58)	20.09 (57)	31.22 (30)	42.04 (4)	.490	.192	.129
Nickel Plate L.	6.70 (51)	14.12 (50)	29.34 (31)	32.26 (19)	.324	.318	.041
Pennask L.	8.38 (40)	15.11 (39)	20.32 (29)	24.18 (15)	.256	.129	.076
Dairy L.	9.25 (166)	27.95 (81)	35.39 (5)	—	.480	.121	—
Glimpse L.	10.20 (173)	27.62 (111)	38.72 (17)	—	.433	.147	—
Kelly L.	6.85 (79)	14.81 (65)	25.18 (24)	33.96 (5)	.335	.231	.130
Big Bar L.	6.45 (194)	16.84 (194)	24.69 (146)	29.66 (29)	.417	.162	.080
Pavilion L.	7.45 (89)	21.14 (79)	38.08 (26)	49.25 (2)	.453	.256	.112
Peterhope L.	8.82 (72)	31.16 (12)	46.80 (4)	55.10 (2)	.548	.177	.071
Garibaldi L.	9.12 (88)	16.33 (83)	22.48 (69)	26.11 (31)	.253	.139	.065
Harper L.	10.08 (109)	26.10 (93)	33.30 (10)	—	.413	.106	—
Jacko L.	7.08 (34)	26.92 (18)	29.62 (2)	—	.580	.042	—
Sunday L.	8.38 (57)	17.78 (49)	24.94 (17)	31.67 (4)	.327	.147	.103
Watch L.	7.49 (64)	27.53 (34)	29.16 (2)	—	.565	.025	—
Kootenay L.	10.32 (172)	26.01 (193)	30.33 (85)	45.27 (37)	.401	.067	.174
Okanagan L.	7.52 (75)	19.02 (73)	30.12 (39)	35.66 (13)	.403	.200	.073
Knouff L.	9.31 (63)	25.51 (35)	35.64 (18)	44.96 (2)	.438	.145	.101
McConnell L.	7.10 (142)	18.53 (84)	27.10 (40)	33.13 (5)	.417	.165	.085
Beaver L.	7.84 (90)	18.08 (89)	25.73 (11)	37.26 (1)	.363	.153	.161
Lac le Jeune	7.55 (156)	17.99 (153)	27.82 (98)	35.06 (31)	.377	.149	.100
Paul L. (1946-49)	9.09 (255)	25.79 (180)	32.99 (68)	36.12 (est.)	.452	.107	.039
Paul L. (1952)	7.50 (438)	16.10 (429)	25.00 (308)	30.50 (30)	.332	.191	.080

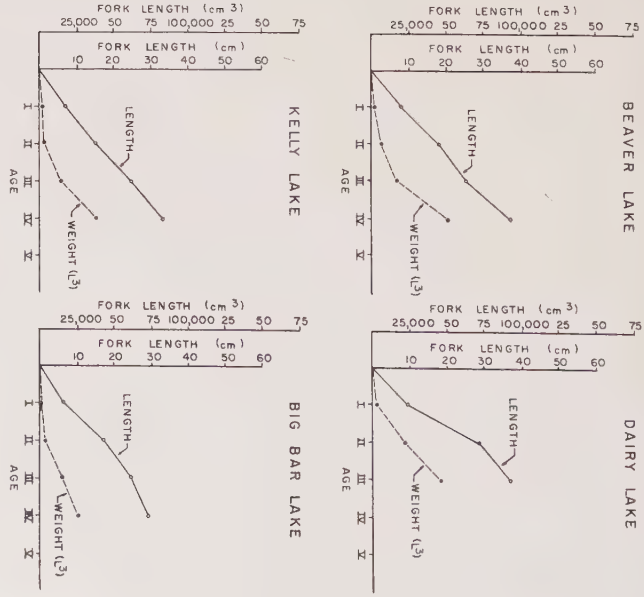
have higher "i_{34}". Similarly, eight lakes have lower "i_{23}" than Lightning, and two have lower "i_{34}". Further comparisons between lakes with the series confirm the same apparent paradox. Jacko Lake has a higher "i_{12}" than Peterhope Lake. Fish do not attain the size at age II as those in Peterhope but the size at age I is smaller than in Peterhope. The highest "i_{23}" occurs in Nickel Plate Lake where slow growth until age II is followed by fairly rapid growth between ages II and III. The highest "i_{31}" occurs in Kootenay Lake where growth is accelerated after age III. Instantaneous annual growth rates are evidently influenced by the size that the fish attained prior to the year of growth in question. Their direct comparison for fish of the same age is only justified when the fish are of comparable size.

Graphic representation of size attained by trout in 16 of these lakes illustrates the effect of lake ecology on growth. Figures 1 to 4 show growth of trout in four relatively unproductive lakes where rainbow trout is the only species of fish present and where there are relatively high population densities. In all cases the rate of growth deteriorates rapidly as the fish grow older and larger. Figures 5 to 8 show moderate growth rates in productive lakes where only Kamloops trout are present and where population densities are relatively low. In this group, growth rates are more rapid but also decline as the fish grow older and larger. The same is true but to a lesser extent of the third group, Figures 9 to 12 which show high growth rates in lakes where there are only Kamloops trout and where population densities are very low in relation to high productivity in the lakes. For the whole series of 12 lakes in which trout are the only species present, growth rate is largely geared to the size of the trout population in relation to the level of lake productivity and appears to be regularly related to the age of trout. Figures 13 to 16 show growth rates of trout in lakes where species of fish other than rainbow trout are also present. They all exhibit characteristics which set them apart from growth curves for lakes containing only trout. The decline in growth rate with age and size is not uniform, suggesting that at certain ages or sizes, changes in the relation between trout and other species of fish are responsible for acceleration or deceleration of changes in growth rate. Evidence presented later in this paper indicates that these changes in growth rate relate to trout becoming piscivorous, a switch in niche that is a function of size of the trout.

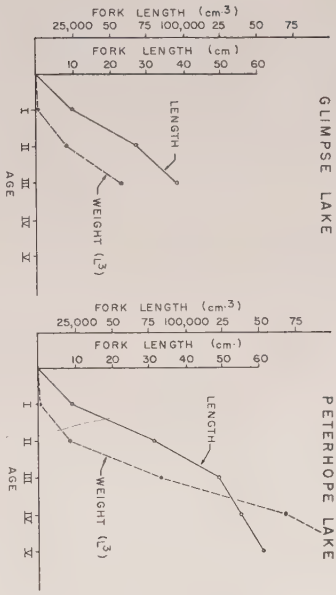
Annual instantaneous growth rates for different ages of trout will thus reflect not only the size of the fish, but also the size in relation to lake ecology. Accordingly it would seem more desirable to dispense with age as a criterion of growth rate and to restrict comparisons to growth rates of fish of the same size *i.e.* plot instantaneous growth rate against specified size. While a relation between age and sexual maturity may be ignored by this procedure it is known that many species of fish

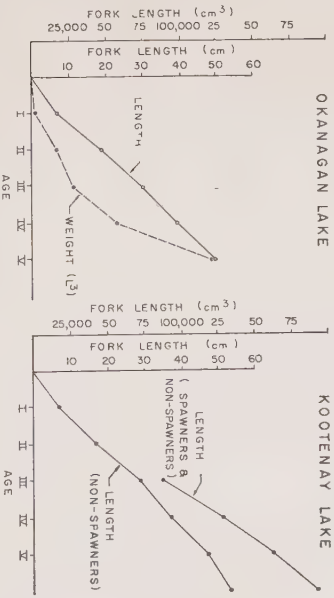


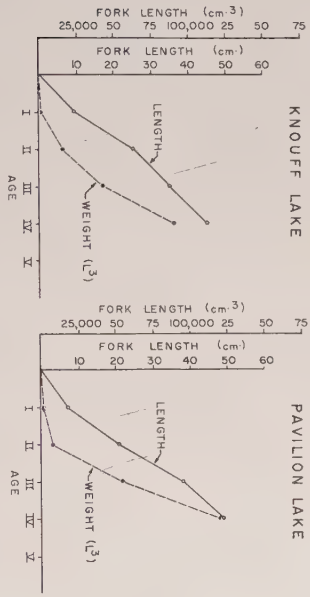
FIGURES 1-4.—Growth in length and weight (length cubed) of rainbow trout in four lakes containing only trout and where the trout are relatively very abundant.



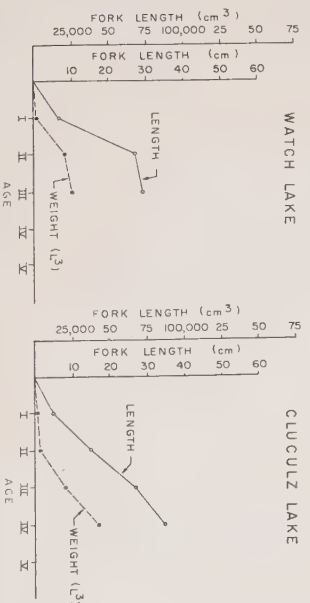
FIGURES 5-8.—Growth in length and weight (length cubed) of rainbow trout in four lakes containing only trout where growth rate is moderate.







FIGURES 9-12.—Growth in length and weight (length cubed) of rainbow trout in four lakes containing only trout where population density is low and growth rate high.



FIGURES 13-16.—Growth in length and weight (length cubed) of rainbow trout in four lakes containing trout and other species of fish.

grow after spawning, and continue to grow measurably over the whole of their life span. Further assessment of age in relation to maturity as it affects growth rate would seem to be useful in suggesting limitations of considering growth rate as a function of size. Three examples of application of "size specific instantaneous growth rates" are given below.

Size Specific Instantaneous Growth Rates

Striking changes in growth of trout in Paul Lake following introduction of the redside shiner *(Richardsonius balteatus),* reported by Larkin and Smith (1954) provide excellent material for testing the usefulness of size specific instantaneous growth rates. In all of the following examples the mean "i" for all fish in a size group was calculated by averaging the "i's" of individuals. It is thus a geometric mean. A schedule of calculations for Paul Lake trout before and shortly after the introduction of shiners is given in Table 2 and the relation between instantaneous annual growth rate (for all ages lumped) and fork length at the beginning of the year is shown in Figure 17. The rapid and relatively uniform growth rate in the earlier period resulted in little overlap in sizes of trout of different ages and there is rather little opportunity for comparison of instantaneous growth rates of fish of the same size but different age. In 1952, however, growth was more variable and slower, and over the range of fork length from 7 to 16 centimeters a large body of data confirms that instantaneous growth rates for the intervals age I and II and age II and III are almost identical for fish of the same size. The same is true for growth between ages II and III compared to growth from III to IV for fish in the range from 14 o 28 centimeters.

Figure 17 clearly indicates the effect of shiners on growth of trout. The lower instantaneous growth rates for all sizes of trout up to the largest in the series is in sharp contrast to the confused picture provided by instantaneous growth rates for different ages given in Table 1. Comparing age specific rates for Paul Lake before and after shiners suggests that the shiners caused slower growth in the first year, somewhat increased growth in the second year and much faster growth in the third year. Figure 17 indicates that these conclusions (which were made by Larkin and Smith, 1954) are artifacts of the relation between size and instantaneous growth rate. Any conclusion that predation on shiners by trout would compensate for the effects of food competition would only be justified if fish of certain *sizes* (large trout chiefly) grew as fast after the introduction as before.

Figure 18 gives size specific instantaneous growth rates for five lakes listed in Table 1. In Figure 18 they lie in a parallel series which except for sampling errors clearly separates and enables quantitative measure of their growth relationships. By contrast comparison of age specific in-

TABLE 2.—*Size specific instantaneous annual growth rates ($\log_{10}$ fork length at age n + 1 minus $\log_{10}$ fork length at age n) for Paul Lake rainbow trout caught in 1952 and caught in the period 1946-1949.*
[Numbers in brackets show numbers in sample].

Fork length centimeters	1946-1949 Instantaneous annual growth rates			1952 Instantaneous annual growth rates		
	i_{12}	i_{23}	i_{34}	i_{12}	i_{23}	i_{34}
3-4	—	—	—	.48772 (8)	—	—
4-5	.65530 (1)	—	—	.44874 (24)	—	—
5-6	.44718 (6)	—	—	.39952 (80)	—	—
6-7	.51243 (24)	—	—	.35464 (126)	—	—
7-8	.51175 (52)	—	—	.32719 (93)	.27065 (2)	—
8-9	.50066 (32)	—	—	.30541 (73)	.40792 (1)	—
9-10	.45572 (35)	—	—	.28799 (44)	.28040 (3)	—
10-11	.40892 (25)	—	—	.26625 (20)	.29683 (19)	—
11-12	.41996 (13)	—	—	.25305 (18)	.25476 (21)	—
12-13	.37784 (7)	—	—	.23491 (4)	.24415 (25)	—
13-14	.31796 (4)	.26144 (2)	—	.20880 (5)	.23774 (51)	—
14-15	.34379 (1)	.32178 (4)	—	.20334 (2)	.22312 (47)	.14834 (1)
15-16	.35157 (1)	—	—	.09807 (1)	.19272 (46)	.17797 (1)
16-17	.27300 (1)	—	—	—	.18731 (36)	.17699 (1)
17-18	—	.21456 (2)	—	—	.18720 (26)	.19098 (1)
18-19	.22419 (1)	.27510 (2)	—	—	.16412 (33)	.17451 (1)
19-20	—	.20001 (4)	—	—	.16040 (22)	.14646 (5)
20-21	—	.19335 (6)	—	—	.14947 (21)	.11753 (5)
21-22	—	.16340 (5)	—	—	.10948 (8)	.11964 (8)
22-23	—	.16925 (5)	—	—	.12619 (10)	.15990 (6)
23-24	—	.14274 (1)	—	—	.10851 (3)	.12436 (7)
24-25	—	.16251 (6)	—	—	—	.09006 (8)
25-26	—	.12057 (1)	—	—	.10721 (1)	.07801 (5)
26-27	—	.11164 (3)	—	—	.11651 (1)	.08262 (5)
27-28	—	.11735 (4)	—	—	.13684 (1)	.06478 (3)
28-29	—	.06639 (2)	—	—	—	.07682 (4)
29-30	—	—	.06908 (1)	—	—	.07568 (3)
30-36	—	.08619 (8)	—	—	—	.06364 (5)

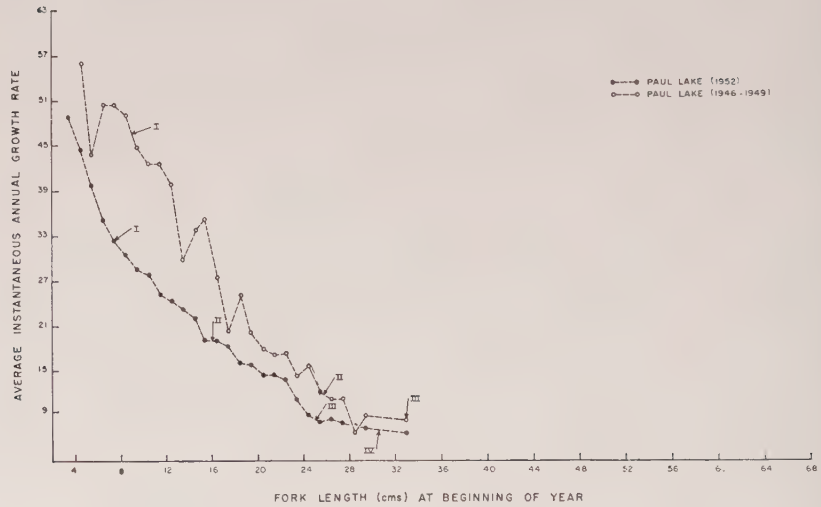


FIGURE 17.— Instantaneous growth rate ($\log_{10}$ fork length at age n+ 1 minus $\log_{10}$ fork length at age n) in relation to fork length at the beginning of the year for rainbow trout in Paul Lake before and after the introduction of the redside shiner *(Richardsonius balteatus)*.

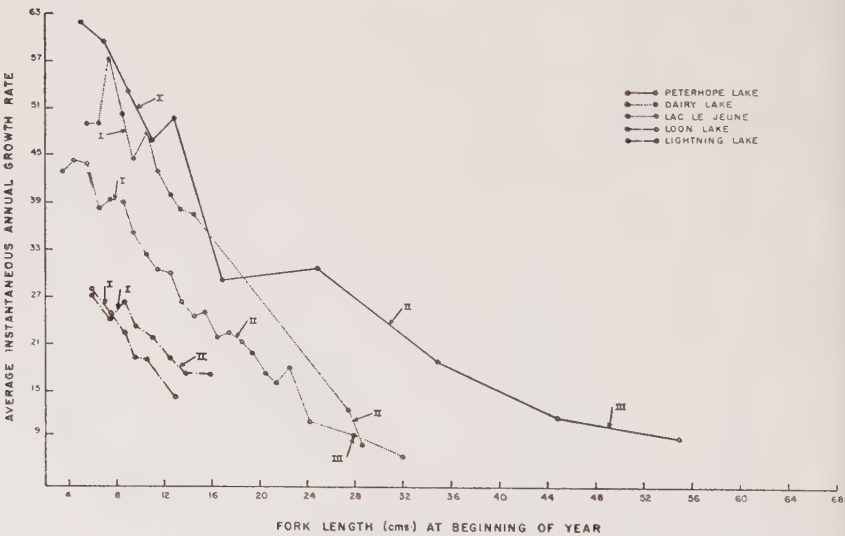


FIGURE 18.—Instantaneous growth rate in relation to fork length at the beginning of the year in five lakes containing only rainbow trout.

stantaneous growth rates does not yield a clear separation of five levels of growth.

A third application of size specific rates is given in Figure 19 which compares Peterhope and Kootenay lakes. Peterhope is a highly productive lake which contains only rainbow trout, which feed chiefly on the rich supplies of plankton and bottom organisms. Kootenay Lake which is large, deep and oligotrophic, affords trout a moderate quantity of plankton but a sparse bottom fauna. The lake contains several other species of fish chief among which the kokanee *(Oncorhynchus nerka)* may be named as a competitor for plankton food and a prey species of large trout. Table 3 indicates the striking difference in food habits of the different sizes of trout in Kootenay Lake. Between the sizes of 33 and 46 centimeters fish (chiefly kokanee) became increasingly important in the diet of trout.

With this brief description of the contrast in the environment for trout in the two lakes an interpretation of the two curves of size specific growth rate in lakes is relatively easy. With the lesser availability of plankton foods trout of small size grow more slowly in Kootenay Lake. At intermediate sizes of from 25 to 30 centimeters the paucity of bottom organisms is reflected in further decline in instantaneous growth rate in Kootenay by comparison with Peterhope. But from 30 centimeters on to the largest sizes the Kootenay Lake rates remain relatively constant because of the

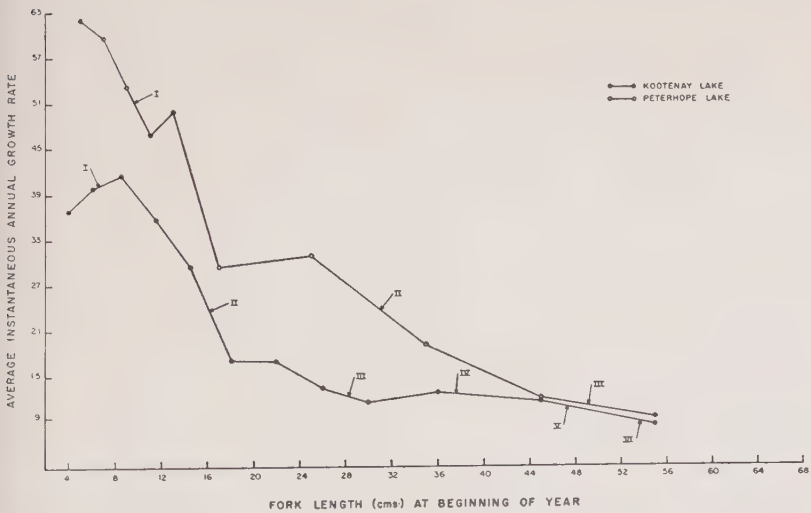


FIGURE 19.—Instantaneous growth rate in relation to fork length at the beginning of the year in Peterhope Lake (trout only) and Kootenay Lake (trout and other species of fish).

predation on fish while those from Peterhope decline. The two curves meet at the largest sizes where Peterhope fish are three years younger than those from Kootenay but grow at the same rate. These observations also contradict the interpretation that could be given to the age specific rates of Table 1.

Relation of Growth Rate to Lake Biology

In lakes that contain only rainbow trout instantaneous growth rate appears to decline rather uniformly as length increases. However, there are marked differences between lakes in the instantanous growth rate for fish of any particular size. This clearly suggests that in each lake, a characteristic "availability" of food organisms determines the ratio of energy gained from food intake to energy expended in living processes. "Availability" may have several components including abundance of food organisms, accessibility of food, efficiency of trout in finding food under varying conditions, behavior of trout in relation to food organisms, behavior of trout in relation to each other and so on. However, the effect of all these factors on growth rate seems to be summarized fairly simply in the order of magnitude and the regular rate of decline of growth rate with size. The slow transition from plankton feeding in young stages to a mixed diet of plankton, bottom fauna and surface insects for larger 'fish (for instance see Larkin *et al.*. 1950) does not appear to constitute a sufficient change in ecology of trout to alter their growth relationship to a lake environment.

The same is not true for lakes that contain other species of fish as well as trout. In both Paul Lake (in recent years) and Kootenay Lake, instantaneous growth rates are not linearly related to size, but show changes with increase in size that reflect alterations in relative "availability" of food. Thus in Paul Lake trout grow slowly at small sizes because of competition with shiners for food, but when the trout attain larger size they prey on shiners *i.e.* the trout embark on a new growth relationship. In Kootenay Lake there is a paucity of bottom organisms which perhaps largely accounts for the rapid deterioration of growth rate with increase in size, but this decline is replaced at fork lengths beyond 20 to 30 centimeters by a higher instantaneous growth rate than would be predicted by linear extrapolation from smaller sizes. It is not surprising that there is no sharp point of inflection indicating a "threshold size" for entering a new growth phase. The growth rates are all calculated on an annual basis and individuals may attain a threshold size (if one exists) part way through a growth season. The switchover to piscivorous habits may not take place suddenly and may be partly influenced by seasonal conditions. Genetic and environmentally induced differences in behavior of individuals may imply a rather broad range of threshold size. How-

TABLE 3.—*Diet of rainbow trout of various sizes in Kootenay Lake (1949)*

Fork length centimeters	Percentage occurrence of food types						Percentage volume of food types					
	Number of specimens	Terr. insects	Bottom organisms	Plankton	Fish	Un-identified	Number of specimens	Terr. insects	Bottom organisms	Plankton	Fish	Un-identified
20—33	107	92.5	36.4	2.8	5.6	6.5	102	67.6	1.3	0.4	28.1	2.6
33—46	26	73.2	19.2	—	23.1	3.8	38	73.9	0.2	—	25.8	0.1
46—91	44	34.1	4.6	—	43.2	6.8	68	13.1	+	—	83.3	3.5

ever, "threshold size" is a useful abstraction in interpreting changes in growth rate.

In summary, expressing growth rate of trout in relation to size, (in this case, fork length) provides a considerably more satisfactory basis for interpreting growth changes than is available using growth rates related to age. Further studies by the authors will develop age, sex, and year class differences in growth rates treated by this method.

Acknowledgments

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ORIGIN AND DISPERSAL OF THE ALEWIFE, *ALOSA PSEUDOHARENGUS*, AND THE GIZZARD SHAD, *DOROSOMA CEPEDIANUM*, IN THE GREAT LAKES

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ABSTRACT

It is possible that the alewife is native to Lake Ontario and the gizzard shad to Lake Erie, although conclusive evidence for this is lacking. There appear to be no records of the alewife from Lake Ontario prior to 1873, after the lake had been stocked with American shad. That species may still occur in Lake Ontario occasionally. A tabular comparison of these species is given to facilitate identification. The alewife is referred to the genus *Alosa* (rather than *Pomolobus)* because no reliable characteristics are available to distinguish the species of these two groups.

Wilmot recorded a herring-like fish (not the American shad) from Lake Ontario about 1837 which probably was the gizzard shad, though it may have been the alewife. The first record of gizzard shad in Lake Ontario is for 1913, but the species was reported from Lake Erie in 1848, 18 years after the completion of the first canal to connect Lake Erie and the Ohio River. It is hypothesized that the gizzard shad entered Lake Erie in pre-Columbian times during a warm-dry period.

A chronological record of the appearance of alewives in the upper Great Lakes shows the first specimen reported from Lake Erie was taken in 1931, Lake Huron 1933, Lake Michigan 1949, and Lake Superior 1954; actual dates of first appearance in each lake are unknown, but the species obviously moved from Lake Erie to the other lakes via Detroit River and Lake St. Clair. The alewife did not become abundant in Lake Erie or Lake Huron until around 1950 or in Lake Michigan until about 1956; it is widely distributed but not yet abundant in Lake Superior. The phenomenal increase in abundance and spreading of the alewife may be correlated with the upset in population balance by the sea lamprey; catch statistics for the alewife and shallow water cisco *(Coregonus artedii)* from South Bay, Lake Huron, suggest a direct or indirect causal relationship during 1954-1956.

The gizzard shad does not occur north of lower New York Harbor (and there only rarely) on the Atlantic slope, although it has been reported from New Brunswick, where it was probably misidentified for the alewife. Its inland range has been extended by canal connections and perhaps it reached Lake Erie in this way; it definitely entered Lake Michigan through the Chicago River canal. A reference in 1874 to the "saw-belly" from the Great Lakes undoubtedly represents the gizzard shad, also known by that name. The species has evidently spread to Lake Ontario and the vicinity of Quebec by moving through the Welland Canal, and to Lake Huron via the Detroit River and Lake St. Clair. The first specimen known to be taken in Lake Michigan was caught on October 13, 1953, west of Muskegon, Michigan; another was taken near Gary, Indiana, on November 2, 1953. The gizzard shad has not been reported from Lake Superior where cold, deep water may prohibit its establishment. It has on occasion gained some commercial importance in Lakes Erie and Huron, where

31,600 pounds valued at $930 were taken in 1949. The gizzard shad may have been aided in expanding northward by the warming climatic trend of the past half century.

The two species, particularly the alewife, are steadily increasing in abundance and methods of utilizing this new resource should be devised.

Introduction

Three species of the herring family, Clupeidae, which is predominantly marine, have been reported from the Great Lakes drainage. The American shad, *Alosa sapidissima* Wilson, has been listed as native to Lake Ontario (*e.g.*, by Hubbs and Lagler, 1947, p. 34), although others claim that it first appeared there when planted by the U.S. Fish Commission in the 1870's (Smith, 1892, pp. 193-194; Evermann and Kendall, 1902, p. 213). The species was last recorded from Lake Ontario in 1931, but it occurs in the lower Ottawa River and stragglers may occasionally reach the lake (Radforth, 1944, pp. 94-95). As detailed below, the alewife, *Alosa pseudoharengus* (Wilson), may have penetrated the Great Lakes drainage from the St. Lawrence River as far as Lake Ontario. It has been able to surmount the barrier of Niagara Falls by passing through the Welland Canal into Lake Erie, from which it has spread throughout the Great Lakes. The gizzard shad, *Dorosoma cepedianum* (LeSueur), probably entered the Great Lakes drainage naturally from the Mississippi River basin via Lake Erie and then moved eastward into Lake Ontario. Its recent occurrence in Lake Michigan, on the other hand, seems clearly the result of immigration through the Chicago River canal; it is unknown in Lake Superior or in the northern parts of Lake Huron and Lake Michigan.

Because fishery biologists and others have difficulty in distinguishing these three species, some of the distinctive external characters are indicated (Table 1) in order to facilitate identification, particularly of young fish. Leim (1924, p. 227, figs. 28-31) gave additional characters that distinguish shad from alewives, including photographs of early life-history stages. An adult gizzard shad (unless injured) is easily recognized by the greatly lengthened last dorsal ray, as well as by the small, inferior mouth and deep body. The position of the dorsal fin, relative length of the anal fin, and comparative size of the upper jaw provide field characters for distinguishing smaller specimens of the three species. Vertebral counts do not overlap between the alewife and the shad or between the gizzard shad and the shad. As Graham (1956, p. 20) has shown, populations of the alewife from Lake Ontario have fewer vertebrae than do those of Atlantic coastal streams.

TABLE 1.—*Comparison between three species of herrings reported from the Great Lakes drainage*

Character	American shad[1]	Alewife[2]	Gizzard shad[3]
Last ray of dorsal fin	Not modified	Not modified	Modified into a long filament (inconspicuous or absent in young)
Origin of dorsal fin	Well before insertion of pelvic fins	Well before insertion of pelvic fins	Over or behind insertion of pelvic fins
Anal fin	Relatively short, with 18-24 rays	Short, with 15-20 rays	Relatively long, with 25-36 rays
Ventral scutes	Typically 22 + 16 = 38 (range, 34-39)	Typically 19 + 14 = 33 (range, 32-37)	Typically 18 + 12 = 30 (range, 27-32)
Longitudinal scale rows	52-64	45-54	52-70
Vertebrae (including hypural)	52-60	47-50	48-51
Upper jaw	Long, slender, its tip reaching posteriorly to middle of pupil in young (25 mm. T.L.) and to beyond eye in adult; no notch	Shorter and wider, its tip reaching to front of pupil in young and to rear of pupil in adult; no notch	Short and moderately wide, its tip scarcely reaching front of eye in young and front of pupil in adult; a slight notch (indentation) along ventral margin in young, becoming a deep notch in adult
Lower jaw	Strong, longer than upper jaw, not fitting into notch in upper jaw	Strong, projecting beyond upper jaw, not fitting into notch in upper jaw	Relatively weak, equal to (young) or shorter than upper jaw, fitting into notch in upper jaw
Mouth	Terminal	Terminal	Subterminal to inferior
Gillrakers	Long, slender, about 25-75 on lower limb in young to adult	Long, slender, about 20-40 on lower limb in young to adult	Very long, fine, close-set, about 90-275 on lower limb in young to adult

[1]Vertebral counts taken from Vladykov and Wallace (1938); number of anal rays in part from Leim (1924, p. 224); gillraker counts approximated from Hildebrand and Schroeder (1928, p. 94).

[2]Counts original, based on Great Lakes and Ontario material only, except for gillraker number which is modified from Hildebrand and Schroeder (1928, p. 89). Leim (1924, p. 206) recorded a variation of 46 to 51 vertebrae in Atlantic Coast alewives.

[3]All counts taken from Miller (1950) except number of gillrakers, which is original.

Alewife

The scientific name of the alewife is generally given as *Pomolobus pseudoharengus* (Wilson). However, Hildebrand and Schroeder (1928, p. 93) indicated that *Pomolobus* and *Alosa* are scarcely distinct and Bailey, Winn and Smith (1954, p. 118) gave further reasons why it seems best to unite them. No clear-cut morphological characters have been proposed to distinguish as a group the species usually placed in *Pomolobus* from those assigned to *Alosa*. Moreover, the name *Pomolobus* probably rests on uncertain nomencatural grounds, for it may be questioned seriously whether Rafinesque's description of *P. chrysochloris* (type species of *Pomolobus*) is based on this genus and species or on the Ohio shad, *Alosa alabamae ohiensis* Evermann (S. F. Hildebrand, unpublished manuscript on the Clupeidae of the Western North Atlantic). Use of *Alosa*, the older of the two generic names, therefore seems preferable.

There is no conclusive evidence that the alewife occurs naturally in Lake Ontario. Bean (1884, p. 589) and others believed it was introduced there by mistake in the 1870's when shad were planted by the U.S. Fish Commission. This has been denied (see Smith, 1892, p. 188), but evidence for nativity is weak since there appear to be neither specimens nor records of the species from Lake Ontario prior to 1873. The possibility that alewives did reach this lake from the St. Lawrence River should not be dismissed, however. Radforth (1944, p. 96) felt that they may have entered Lake Ontario during the invasion of the Champlain Sea, in the later stages of the glacial history of the Great Lakes. Toner (1934) pointed out that its presence in certain lakes whose outlets pass over barrier falls in Frontenac and Leeds counties, eastern Ontario, disproves the claim that the alewife was planted in Lake Ontario. Possibly the species reached its limits of toleration in Lake Ontario and in favorable seasons was able to establish sizable populations which were decimated during inimical years, when presumably only the hardiest individuals persisted. Since around 1890, the alewife has intermittently appeared in Lake Ontario in almost incredible numbers, as noted during periodic summer die-offs (Graham, 1956, p. 21). Whether such comparative abundance reflects recency of introduction is problematical.

The historical appearance of the alewife in the upper Great Lakes, as evidenced by captures known to the author, is given in chronological order (Table 2). The first specimen was taken in Lake Erie in 1931, in Lake Huron in 1933, in Lake Michigan in 1949 and in Lake Superior in 1954. This clearly establishes the sequence of its invasion of these lakes but the dates of first appearance in each lake are not known. As Dr. M. B. Trautman pointed out *(in litt.)*, there must have been thousands of alewives in Lake Erie in 1931 before one could be caught in a net. Nevertheless, the species apparently did not really become abundant there until about 1950, although commercial fishermen caught alewives infrequently, in Ohio waters, after 1940, and there were similar reports from the Cana-

TABLE 2.—*Spread of the alewife in the upper Great Lakes*

Date	Locality	Remarks[1]
Sept. 23, 1931	L. Erie, at E. end off Nanticoke, Ont.	Adult, 7¾ in. long (Dymond, 1932).
Mar. 28, 1933	L. Huron, 12 mi. E. of Outer Duck Id., Ont.	Adult, from about 70 fathoms; others reported (MacKay, 1934).
April 15, 1935	L. Huron, 40 mi. from Rogers City, Mich.	Adult, 188 mm. S. L., from 70 fathoms; UMMZ No. 109109 (Van Oosten, 1935).
Dec. 26-31, 1940	L. Erie, off South Bass Id., Ohio	Adult, 9 in. T. L. taken in gillnet by K. H. Doan (Trautman, 1957).
Dec. 27, 1942	L. Erie, near Vermillion and Lorain, Ohio	Two adults taken in gillnet by fishermen (Trautman, 1957).
May 5, 1949	L. Michigan, W. of S. Manitou Id., Mich.	Adult, 176 mm. S. L., from 60 fathoms, Charles Anderson; UMMZ No. 157215.
Mar. 20, 1951[2]	L. Michigan, off Whitehall, 14 mi. SW. of Montague, Mich.	Adult, 197 mm. S. L., from 60 fathoms, James Grover; UMMZ No. 160969 (see The Fisherman, Vol. 19, No. 5, 1951, p. 6).
Mar. 12, 1952	L. Michigan, 10 mi. ENE. of Milwaukee, Wisc.	Adult, 177 mm. S. L., Frank Miller; UMMZ No. 162861.
July 13, 1953	L. Erie, on beach W. of Colchester, Ont.	Young-of-the-year taken with gizzard shad (Langlois, 1954, p. 207).
July 14, 1953	L. Erie, South Bass Id., Ohio	Young-of-the year (Langlois, 1954, p. 207).
Dec. 22, 1953[3]	L. Michigan, 12 mi. WNW. of South Haven, Mich.	Adults, 180 and 188 mm. S. L., from 32 fathoms, Chris Jensen; UMMZ No. 166514.
Sept. 25, 1954	L. Superior, off Pendill's Cr., Chippewa Co., Mich.	Adult, 168 mm. S. L., Robert Gordon; UMMZ No. 167872.
Nov., 1954	L. Superior, Chequamegon Bay, off Long Id., Wisc.	Adult, 164 mm. S. L., obtained by Russell Daly; UMMZ No. 167945.
June 1 & 14, 1955	L. Superior, Whitefish Bay, about 1 mi. N. of mouth of Tahquamenon R., Mich.	Adults, 162 and 175 mm. S. L., from pound net, Ernest L. Pomeroy.
June 3, 1955	L. Huron drainage: Ocqueoc R. Weir near Rogers City, Mich.	Adults, 179 and 182 mm. S. L., Albert E. Hall, Jr.; UMMZ No. 169062.
June 10, 1955	L. Superior, Whitefish Bay, Mich.	Adult, 197 mm. S. L., sent in by L. R. Anderson.
June 11, 1955	L. Michigan, East Bay of Grand Traverse Bay, Mich.	19 juveniles, 55-76 mm. S. L., bait dealer for Stanley Lievense; UMMZ No. 170945.
Sept. 14, 1955	L. Huron, along shore in the Les Cheneaux Channels, Mackinac Co., Mich.	Fingerlings, about 2 in. T. L., bait dealer; ident. by L. R. Anderson.
Oct. 17 and Nov. 12, 1955	L. Superior, Gros Cap area near Sault St. Marie, Ont.	Adult male (210 mm. T. L.) and adult female (273 mm. T. L.), ident. by K. H. Loftus and W. B. Scott; ROM No. 18157 (male).
Feb. 13, 1956	L. Superior, off Two Harbors, Minn.	Adult from herring net, Adolph Ojard; ident. by John G. Hale and Samuel Eddy.

TABLE 2—Continued

Date	Locality	Remarks[1]
March, 1956	L. Superior, off Knife R., Minn.	Adult taken by Ivar Pederson; ident. by John G. Hale.
June 6, 1956	L. Superior, at mouth of Blind Sucker R., Luce Co., Mich.	Adult, 9½ in. long, caught by George McGary; 2 other adults also taken. Ident. by L. R. Anderson.
July 31, 1956	L. Superior, Split Rock R. area, Minn.	Adult, 161 mm. S. L., from herring net, Ragnivald Sve.
Aug. 31, 1956	L. Superior, off Shaganance Id. (near entrance to Black Bay), Ont.	Adult male, 166 mm. S. L., taken by Melville Gerow; ident. by R. A. Ryder.
Sept. 10, 1956[2]	L. Michigan, East Bay of Grand Traverse Bay at O-at-ka Beach, Mich.	341 postlarvae to young, 19-40 mm. S. L., taken in minnow seine for Stanley Lievense; UMMZ No. 171308.
Nov. 5, 1956	L. Superior, Keweenaw Bay, 1 mi. off town of same name, Mich.	Adult, 181 mm. S. L., from surface gillnet over 17 fathoms, taken by Uno Weideman.

[1]Abbreviations are: S.L. standard length; T.L., total length; UMMZ, University of Michigan Museum of Zoology; ROM, Royal Ontario Museum.

[2]Approximate date.

[3]On April 24, May 10, and Oct. 20, 1954, 3 more adults were taken in 32-50 fathoms by Mr. Jensen from the same general area; UMMZ No. 167702.

dian waters of Lake Erie. "After 1950 the young and adults [alewives] were sufficiently numerous so that they were distributed rather regularly throughout Lake Erie. In December, 1954, they clogged the gill and fyke nets in the vicinity of Conneaut, Ohio, following a bad storm" (Trautman, *in litt.*, Dec. 20, 1956). This information is supported by Dr. W. B. Scott who wrote (*in litt.*, March 5, 1954) that ". . . in the last four or five years the alewife has definitely increased in numbers in Lake Erie." The Welland Canal has been available for this highly migratory species since 1829, and yet we have no knowledge of its occurrence in Lake Erie until 1931 (or of the equally migratory sea lamprey before 1921).

The rather sensational increase in abundance and spread of the alewife during the past decade has probably resulted from a number of changes particularly favorable to this species. Important modifications in the complex interrelationships of the native fauna have been brought about by the sea lamprey, *Petromyzon marinus*, and these disturbances may have influenced the change in alewife abundance. We do not yet have, however, sufficient biological information to be able to draw conclusions on this problem. The lake herring and alewife may compete for food and space at some stage in their life cycles since the adults rely heavily on animal

plankton. Locally, as at South Bay (Table 3), Saginaw Bay and Green Bay (information from Stanford H. Smith), the alewife populations have recently increased greatly while the lake herring stocks have decreased. Possibly, newly metamorphosed lampreys migrating across these bays to deeper water have helped to reduce the lake herrings; or, the decrease (particularly noteworthy in these bays in 1954, 1955, and 1956) may be a result of normal population fluctuation. That it has occurred simultaneously in the three bays, however, suggests some degree of causal relationship, direct or indirect, between the alewife, lake herring and lamprey (and possibly other species).

The alewife is now abundant in many parts of Lake Huron and Lake Michigan. During the period May 6, 1954, to March 10, 1955, when the U. S. Fish and Wildlife Service research vessel M/V CISCO made thirteen cruises in the southern part of Lake Michigan (mostly south of a line joining Milwaukee and Grand Haven, but north to a line joining Manitowoc and Ludington), no alewives were caught. On the other hand, during nine similar cruises in the northern half of Lake Michigan, over the period May 10 to November 12, 1955, 21 alewives were taken from 10 stations. Nevertheless, by late 1953 the alewife had moved as far southward in Lake Michigan as the vicinity of South Haven (Table 2, item 11). Moreover, in a memorandum dated January 2, 1957, Max A. Hunt (District Fisheries Supervisor, Plainwell, Michigan) reported that "Commercial fishermen, fishing out of Saugatuck, report the alewife is being caught in their "chub" nets in up to 43 fathoms of water. There have been 200-300 fish taken in a single lift. The fishermen are complaining about the alewife fouling their nets." Saugatuck is about 20 miles north of South Haven and well within the southern half of Lake Michigan.

The author is indebted to Leonard S. Joeris for the following information on the alewife in the Green Bay area of Lake Michigan. The first indication of spawning was noted in October, 1953, when two or three schools of small alewives were present in the carp-holding ponds near Duck Creek, Wisconsin (at the southern tip of Green Bay). Additional reliable reports of schools of young were received in the early fall of 1954 and

TABLE 3.—*Catch of alewife and lake herring in South Bay, Lake Huron, Ontario* (all fish taken in 1½ inch mesh five-pound nets fished in same location)

Year	Pounds alewife	Pounds herring	Number of lifts
1951	0.2 (1 fish)	36,018	175
1952	1.0 (5 fish)	14,119	163
1953	6.0 (51 fish)	12,625	65
1954	2,316	8,731	97
1955	16,302	4,841	86
1956[1]	22,428	3,476	93

[1]Figures for 1956 are provisional, subject to checking, but final figures could vary only a few pounds from those given.

1955. The number of adults has increased yearly from a single individual in 1952 to common occurrence by 1955 in all herring pound nets—yet not in sufficient numbers to cause difficulty for the fishermen. By the spring of 1956, however, fishermen in the Ellison Bay and Gills Rock area (on the eastern side of Green Bay) were becoming quite concerned by the continuing increase of the alewife. A steady increase in numbers has also occurred for the gillnet fishery along the northern part of Green Bay and Lake Michigan.

Alewives are now abundant in the Saginaw Bay area of Lake Huron. For example, during operations of the CISCO over the period May 3 to October 25, 1953, 6 of 9 cruises caught this species. While trawling in a very shallow area near the southwest end of the Bay, about 6,000 alewives, 1.5 to 3.0 inches long, were taken in a 35-foot trawl in one 5-minute bottom tow, and 8,500 were caught in a 5-minute tow just off the bottom. Over 50 percent of all fishes caught in trawling operations by the CISCO were alewives (information from Stanford H. Smith).

Records up to the fall of 1956 suggest that the alewife may not yet have established itself in numbers in Lake Superior although it has rapidly dispersed there. The CISCO ran nine cruises on the lake during May 3 to October 25, 1953, and took no alewives, although their nets were fished in some of the regions from which the species was obtained soon thereafter (Table 2.)

Van Oosten (1935) felt that the alewife probably entered Lake Huron through Georgian Bay directly from Lake Ontario via the Trent River-Trent Canal-Lake Simcoe-Severn River waterway, rather than by way of the Detroit River and Lake St. Clair, since the species had not been reported from the last two areas. In response to my query regarding this possibility, Dr. W. B. Scott wrote (Jan. 2, 1957) that there are no records of this species (or of *Petromyzon, Osmerus* or *Anguilla)* from Lake Simcoe, or any other major portion of the waterway, even though the habitat there seems to be excellent for all of these fishes. The proposed route is a very involved, even tortuous one, and the water flows through hydroelectric plants at two marine railways at the western end of the system. Failure to take alewives in Detroit River is not surprising, since organized collecting there (as by the Michigan Institute for Fisheries Research) has been carried out chiefly in shallower waters than those which the alewife habitually seeks. Radforth (1944, pp. 95-96) also concluded that the alewife reached Lake Huron via the Detroit River and Lake St. Clair.

It seems evident that the alewife will become increasingly abundant in the Great Lakes and that utilization of this new resource should be encouraged. The species may well establish itself, by distribution in bait[1] buckets, in such inland lakes as Crystal Lake, Benzie County, Michigan.

[1]On July 6, 1956, an alewife 139 mm. S.L. was taken by I. A. Rodeheffer and J. K. Day in Mullet Lake, Cheboygan Co., Michigan (specimen in UMMZ collection).

According to Robert Heffner, bait dealer from Beulah, it occurs nearby in Betsie River, near Frankfort, and at the mouth of Platte River; he has observed dense schools of alewives at sizes up to 4 inches at Frankfort. Although they do not survive well when collected in large numbers, a few do live and it is difficult to sort them all out from bait species. Alewives have been used in Lake Ontario as a ready source of cheap food as well as for fertilizer, and on the Atlantic coast they are marketed fresh, smoked or pickled.

Gizzard Shad

Discussion regarding the northern limit of this species, both for the Atlantic seaboard and for the Great Lakes-St. Lawrence basins, has been frequently published. Early errors in range statements and evidently in identification have led to subsequent confusion. Some of the controversy, however, also hinges on the question of whether *Dorosoma* is native in the Great Lakes drainage.

At least as early as the 1870's, Gill (1873, p. 811) erred by including Cape Cod in the distribution of this species. Subsequently, Jordan and Gilbert (1883, p. 271) and others perpetuated the error. The author has been unable to discover the basis for listing Cape Cod as the northern limit of the gizzard shad on the Atlantic seaboard, but the locality has persisted in the literature almost to the present (e.g., see Vladykov, 1945, p. 36). *D. cepedianum* is uncommon north of latitude 40° N. in New Jersey and southeastern Pennsylvania, and reaches its northern coastal limit in New York Harbor, usually called the Lower Bay or Sandy Hook Bay (Breder and Nigrelli, 1934, p. 194; Breder, 1938, pp. 23, 28). Halkett (1913, p. 46) stated that this species has been recorded from St. John River, Fredericton, New Brunswick, and this formed the basis of the inclusion of New Brunswick in the range of *Dorosoma cepedianum* by Hubbs and Lagler (1947, p. 34) and by Radforth (1944, p. 58). As pointed out by Vladykov *(op. cit.),* the New Brunswick record is based upon the remarks of an unknown author, who, in a review of Nash's Check List of the Fishes of Ontario, wrote of *D. cepedianum:* " . . .it is a native Canadian fish, and was recorded by the late Edward Jack on the St. John River, at Fredericton, N. B. . . ." The St. John River is a tributary of the Bay of Fundy and its mouth lies more than 500 miles northeast of the northernmost known coastal limit of *Dorosoma.* This record is therefore unacceptable; the fish thought to have been a gizzard shad very likely was the alewife, which occurs as far north as Newfoundland and has been confused with the gizzard shad.

Kirtland (1850, p. 2) appears to have been the first to suggest that *Dorosoma* entered the Great Lakes (i.e., Lake Erie) via canal connections, and this belief has been variously accepted and restated by subsequent authors during the succeeding century. The problem is complicated by the

very different physical conditions of Lake Michigan and Lake Erie, the only two of the Great Lakes which offered direct access to the gizzard shad in glacial or postglacial times. More than a dozen species, representing three families, show a distributional pattern in Michigan that clearly indicates penetration from the south into southeastern Michigan. These fishes invaded the Lake Erie basin by utilizing the former outlet (now Maumee River) of the glacial precursor of Lake Erie, or by way of other natural connections across the very low divide between that basin and the Mississippi River system. Yet not one of these species is known from the adjacent drainage of Lake Michigan. It seems evident that the colder, deeper water of that lake has served as an effective barrier to these fishes, as it evidently has, until very recently, to the gizzard shad. Thus, although this species was reported by Nelson (1876, p. 44) from the Chicago River canal and Lake Michigan, there is no objective evidence to show that the gizzard shad established itself in the lake by migration from the Illinois River until recent years. There are no specimens of this species from the southern tip of Lake Michigan in the Chicago Natural History Museum (or any other collection), and Forbes and Richardson (1919, Map 8) gave no records nearer Lake Michigan than the junction of Fox and Illinois Rivers in La Salle County, Illinois; furthermore, Gerking (1945, Map 8) did not find it in the Lake Michigan drainage of Indiana.

Whether *Dorosoma* is native to Lake Erie cannot be solved conclusively because, to the author's knowledge, there are neither specimens nor records of gizzard shad from this lake prior to the completion in 1830 of the first canal connecting the Ohio River with Lake Erie. The first specimens of *Dorosoma* to be reported from the Great Lakes were four fish recorded by Kirtland *(loc. cit.)* in November, 1848, from near the mouth of the Cuyahoga River at Cleveland. He was certain that this species did not occur in Lake Erie or its tributaries in 1840, and believed the specimens captured in 1848 represented recent invaders from the south. Kirtland was perhaps overimpressed by the winterkill of many gizzard shad during a hard freeze in the Dayton Canal, since he cited this as evidence that *Dorosoma* "was a native of a warmer climate." He was also impressed with the failure of fishermen to recognize the gizzard shad near Cincinnati much before 1840 and with their stated belief that it was an emigrant from the south. Klippert (in Jordan, 1882, pp. 870-871) also believed that the gizzard shad was not native to Lake Erie; he wrote that "before the construction of the Ohio Canal it was not found anywhere north of the divide, or water shed between the lake [Erie] and the Ohio River." According to Jordan *(op. cit.*, p. 742), Mr John H. Klippert was "a close observer and excellent amateur ichthyologist."

In November, 1877, Samuel Wilmot (1879) collected a specimen of *D. cepedianum* from Sarnia, Ontario, at the southern tip of Lake Huron. It was identified by Baird as *Dorosoma cepedianum heterurum* and the author has verified that it is a gizzard shad (USNM No. 20836). In transmitting

this specimen, Wilmot wrote that "Fish very similar in appearance to this one have been known in Lake Ontario and other of our waters for many years; I recollect them forty years ago." This would have been about 1837. Wilmot was a pioneer fish culturist and supervisor of the Canadian salmon hatchery at Newcastle on Lake Ontario (Milner, 1874, pp. 25, 58, 228, 231), and he surely knew the American shad; his testimony strongly suggests that the gizzard shad inhabited the Lake Ontario basin as early as 1837, although it is possible that the species he referred to may have been the alewife. The first published record of the gizzard shad in Lake Ontario that I have noted is for 1913, when Nash reported the species to be very rare (see Dymond, Hart and Pritchard, 1929, p. 14). Since it is now known from an actual specimen that *Dorosoma* occurred in Lake Huron in the 1870's, it seems obvious that the reference by Milner (1874, p. 36) to the "saw-belly," identified as *Pomolobus chrysochloris* Rafinesque, actually represents one of the early records of *Dorosoma cepedianum* from the Great Lakes (which lake was not specified). This conclusion was first expressed by Hubbs and Lagler (1947, footnote, p. 34).

Although the possibility that Dorosoma first entered Lake Erie through canals cannot be ruled out, it is perhaps more plausible to regard this species as a postglacial migrant into Lake Erie. This view is favored by Trautman (1957). On the northern fringe of its range *Dorosoma* is near the limit of its thermal tolerance, forging northward during a series of favorable years and then, under adverse conditions, becoming almost eliminated (see, for example, Cox, 1896, p. 610). When numbers are killed and fishermen see the species for the first time, they fail to recognize it and conclude that it is a recent invader from a more southern clime. Dr. Trautman wrote me that this has happened innumerable times in Ohio since Kirtland's day. Perhaps the gizzard shad gained access to Lake Erie during a warm-dry period in pre-Columbian times and then, with the retrun to present conditions, it retreated but left relict populations. *Dorosoma* is favored to establish outlying colonies because spawning adults enter small streams or ditches, provided they are of low gradient, and the young are later abundant there. In early historic time, there were many places along the divide between the Ohio and Lake Erie watersheds (e.g., the close approach of the Maumee and Wabash drainages near Ft. Wayne, (Indiana) where *Dorosoma* could readily have crossed from one drainage to the other. It is also possible, as Gerking (1945, p. 33) suggested, that the gizzard shad may have entered the glacial precursor of Lake Erie through the Ft. Wayne outlet (Maumee River), but this view seems less acceptable because *Dorosoma* does not appear to be adapted to very cold water, such as prevailed during the melting of the continental glaciers in the evolution of the Great Lakes. The species occurs in the Great Lakes drainage of Indiana only in the Maumee River system (Gerking, *op. cit.*, Map 8). There appears to be no need for nor support of the hypothesis (Radforth, *loc. cit.)* that *Dorosoma* utilized the Mohawk-Hudson glacial

outlet (or the Chicago-Ubly outlet) to enter Ontario; if it uilized glacial waterways at all, the Maumee outlet seems to be the only possible one that it might have entered. Vladykov *(op. cit.)* concluded that this species reached the environs of Quebec by descending the St. Lawrence River from the Great Lakes.

Thus the gizzard shad, as perhaps with the alewife in Lake Ontario, apparently neared the limit of its tolerance in Lake Erie. Its increase and spread in the lower Lakes may well reflect the known warming climatic trend (Baum and Havens, 1956) or may be a response to changing biotic conditions of the Great Lakes in recent decades—or both phenomena may be operative. That the species has entered canals and thus extended its range seems well founded (e.g., see Wright, 1918, p. 544; Greeley, 1928, p. 95).

The first valid records (based on identified, preserved specimens) of *Dorsoma cepedianum* from Lake Michigan are the following: UMMZ No. 165645, an adult, 255 mm. S. L., taken by the McNab brothers, on October 13, 1953, in a trap net in 14 feet of water about 1 mile south of the channel connecting Lake Michigan and Muskegon Lake, west of Muskegon, Michigan. A second specimen, an immature female in poor condition identified by the author and then discarded, was obtained by D. C. Erlandson from a pound net set in 25 feet of water, on November 2, 1953, off Miller, 5 miles east of Gary, Indiana. The evidence clearly points to a southern origin for these stocks, since no specimens have been reported in the northern half of Lake Michigan or in northwestern Lake Huron. *Dorosoma* has thus gradually extended its range into Lake Huron by emigration from Lake Erie and into Lake Michigan through the Chicago River Canal. The gizzard shad has not been reported from Lake Superior, where low temperature and the absence of shallow water may preclude its establishment.

This species has had a long history of fluctuating abundance in Lake Erie but it evidently has rather recently established itself in numbers in certain parts of Lake Huron. For example, Bensley (1915) did not record it from Georgian Bay, and when Walter Koelz collected a specimen there late in 1919 (UMMZ No. 55632), fishermen informed him that the gizzard shad had rather recently appeared and that all those taken were small. Today the species is fairly common in suitable parts of Georgian Bay. It was so abundant in Detroit River and Lake St. Clair in the fall of 1932 that unemployed persons caught them for food with dipnets and hook and line. By October 7, 1933, the gizzard shad had moved inland up the Saginaw River drainage as far as Pine River at St. Louis, Gratiot Co., Michigan (UMMZ No. 101607, 1 adult); this is one of the few records of its occurrence well inland from the Great Lakes and populations have not established themselves at appreciable distances inland. An attempt was made to establish the species in Whitmore Lake, Washtenaw and Livingston Counties, Michigan, in August, 1935, when the Michigan Institute for Fisheries Research stocked 124 individuals (1.5 to 15.0 inches S. L.)

from Lake St. Mary's, Ohio. It is estimated that 100 adult shad survived after one week, but if so, successful reproduction did not occur and the introduction failed (IFR Report No. 315; see also Cooper and Schafer, 1954).

Abundance in lakes Erie and Huron since about 1940 is indicated by the commercial catch statistics (U. S. Fish and Wildlife Service and Michigan Department of Conservation) which show that a total of approximately 116,000 pounds valued at $2,300 were taken during the period from 1942 to 1954. The largest catch for a single year, 31,600 pounds valued at $930, was taken in 1949. Occasionally, sudden mortality of vast numbers (similar to that of the alewife in Lake Ontario) creates a public nuisance, as it did at Erie, Pennsylvania, during January-February, 1953. (This and other aspects of the biology of the gizzard shad are summarized by me in a paper to be published by the U. S. Fish and Wildlife Service entitled: "The clupeid fishes of the subfamily Dorosomatinae, with special reference to the gizzard shad, *Dorosoma cepedianum.*")

The gizzard shad is not as widespread in the Great Lakes as the alewife, probably because its preferred habitat is less extensive, and, except locally, it is not likey to attain or exceed the popuation size of that species. It has been utilized in the Great Lakes as a source of food for trout, swine and cattle, as fertilizer, and it has been steamed and pressed for oil.

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STUDIES OF SMALLMOUTH BLACK BASS *(MICROPTERUS DOLOMIEU)* IN THE COLUMBIA RIVER NEAR RICHLAND, WASHINGTON

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ABSTRACT

Observations on smallmouth black bass, *Micropterus dolomieu,* of the Columbia River were possible because of a transplantation program undertaken by local sportsmen and because of studies made by the U. S. Public Health Service and the General Electric Company to evaluate effects of the radioactive effluent from the Hanford reactors. The average bass caught with sport-fishing gear was 15½ inches long and weighed 40 ounces. Females were larger and made up a greater portion of the catch than males. Age was from three to eleven years but seven and eight-year-old fish made up about half of the catch. Growth was rapid in spite of a short season and water temperatures below that considered optimum.

Some spawning occured in sloughs as early as April, but was unsuccessful because of a subsequent drop in temperature. Fry hatched from eggs spawned in July and August when temperatures were from 60 to 75°F. Transplanted bass move about considerably, but a definite migratory pattern was not established. Some fish moved over forty miles and many returned to the place of initial capture.

Radioactive materials, which originated in the effluent from the reactors, were acquired by the bass through food chains. The principal isotope concentrated in the fish and other river animals was radiophosphorus. The level of radioactivity in the bass was greatest in September and least in April. No adverse effects on bass or food organisms, attributable to radioactive effluents, could be detected. The radioactive contamination of the bass was too low to constitute a hazard to persons who might eat them.

Introduction

Studies of smallmouth black bass have been made in many sections of the United States and Canada. However, there is a scarcity of information on these fish in cold water streams of the far West.

A population of smallmouth black bass has existed in a section of the Columbia River near the southeastern corner of the State of Washington for a number of years. Very few anglers fished for these bass prior to World War II. In 1942, construction of the plutonium-producing nuclear reactors was begun near the townsite of Hanford (Figure 1) and access to this area was restricted from the general public. Many of the workers recruited for the construction and operation of the new atomic energy plants came from the eastern and southern parts of the United States and were ardent bass fishermen. These people, now residents of the government-built town of Richland, enjoyed excellent bass fishing in the Yakima River and in the unrestricted section of the Columbia for two or three years before the near-virgin bass populations were reduced in number. In hopes of bolstering the populations, the Richland Rod and Gun Club obtained permission from the Atomic Energy Commission to enter the restricted area and utilize the unexploited bass living in that section of the Columbia River. A project of transplanting adult bass from the restricted area to the Yakima was initiated in the spring of 1950 with the assistance of the Washington State Department of Game and aquatic biologists of the General Electric Company[1] (Johnson and Foster, 1950; Foster, 1951).

Aquatic biologists of the Public Health Service[2] participated in this work during 1951, 1952, and 1953, and made additional observations on the smallmouth bass in connection with their studies on the effects of radioactive effluent on river organisms (Robeck, Henderson, and Palange, 1954).

The transplantation project, together with information collected to evaluate effects of the effluent, provided a substantial block of data for study of the life history of the smallmouth bass in this part of the Columbia River.

The Sport Fishery

Largemouth black bass, *Micropterus salmoides*, have been widely introduced into lakes and potholes of the semi-desert regions of central and eastern Washington. In fact, some of the finest largemouth fishing in the country has been in the equalizing reservoir of the Grand Coulee irrigation project and other lakes and potholes of the region. While a few of

[1]The General Electric Company operates the Hanford plants for the Atomic Energy Commission and conducts studies on aquatic life as a part of its investigation of effects of process effluents on plant and animal forms.
[2]The U. S. Public Health Service conducted water quality studies on the Columbia River in the vicinity of the Atomic Energy plants from early 1951 to mid-1953.

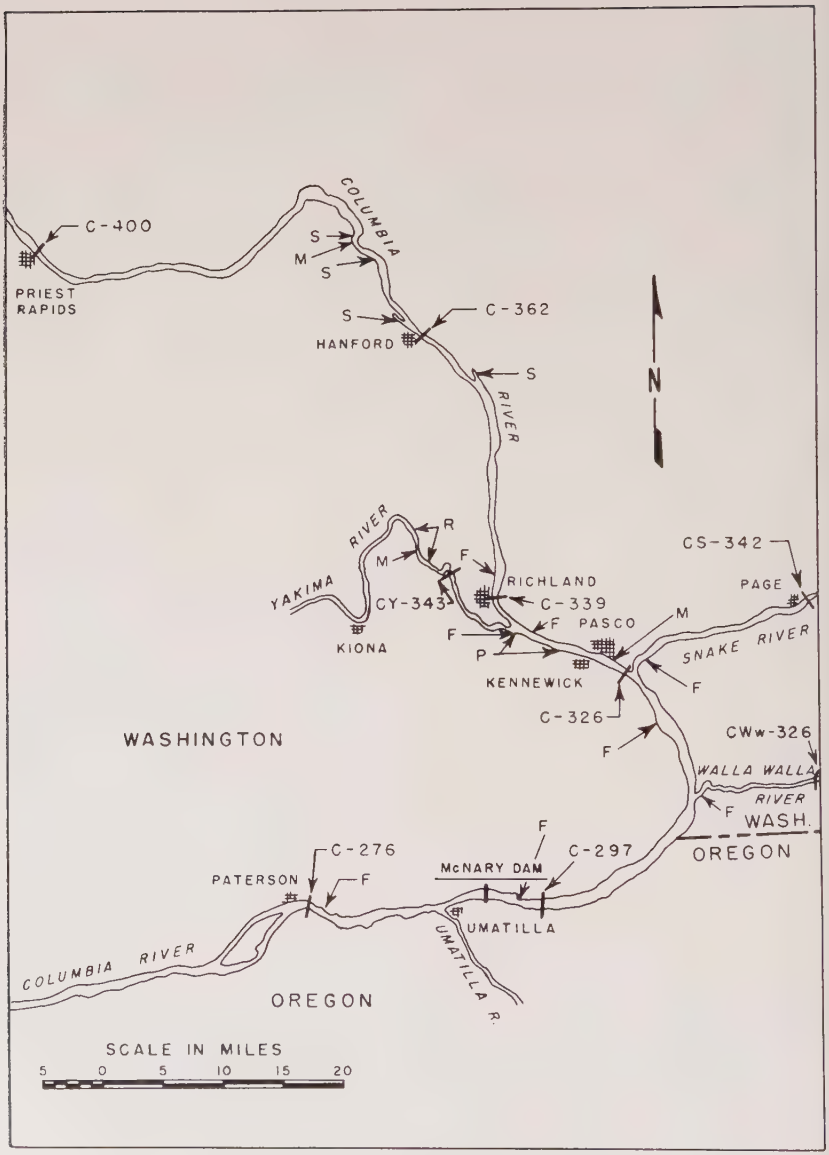

FIGURE 1.—The Columbia River in the vicinity of Richland, Washington. C — 400 miles upstream from the mouth of the Columbia River. S — Sloughs where bass were initially captured. R — Points of release. F — Bass fishing areas. P — Principal areas of recapture. M — Maximum distance up and downriver where bass were recaptured.

these fish may find their way into the Columbia, they are not generally abundant in the main river. This fishery receives little attention as trout, steelhead, and salmon are also abundant in this region and are preferred by sport fishermen.

Smallmouth bass are much less abundant in this region and are generally found only in the Columbia River and near the mouths of some of the large tributaries. Local fishermen reported that smallmouth bass were planted in the lower Snake and Yakima Rivers in the early 1930's. No doubt other plants have been made as these fish have been reported from the Columbia River as far north as the mouth of the Kettle River above Grand Coulee Dam and downstream to below Bonneville Dam. Sport fishing for bass in the Columbia River is generally limited to a few weeks in the spring, usually April and early May, before the advent of high water. The fish congregate in the slough areas where the water warms faster than in the main channel. Phenomenal success is enjoyed by fishermen until the water rises and colder water starts passing through the sloughs. After the high water recedes, generally late August or September, the river temperature rises and bass move back into the main channels. Fishing becomes fair in some areas during September and October, but receives little attention as most fishermen are interested in the large runs of steelhead and salmon which occur at this time. Fishing in the tributaries, particularly the Snake and Yakima Rivers, is fair during the summer and fall months and the few ardent bass fishermen are rewarded with some good catches. From personal observations by the senior author, smallmouth bass fishing in the Yakima River compares favorably with some of the better bass streams in the East. Catches of large smallmouth bass from the Columbia River sloughs during the few weeks of exceptionally good fishing in the spring far exceded any made by the senior author during any period while fishing in the Shenandoah and Potomac River systems of Virginia and West Virginia

Limnological Conditions

The physical, chemical, and ecological characteristics of this section of the Columbia River have been reviewed in detail in a report by the Public Health Service (Robeck *et al.*, 1954). Since these conditions may affect the well-being of bass, they are briefly summarized here.

Stream discharge follows a seasonal pattern with high flows in the vicinity of Richland of about 300,000 to 500,000 cubic feet per second occurring between May and July and flows of 50,000 to 70,000 cubic feet per second occurring during the remainder of the year. Tributary flows follow a similar pattern, but the peak runoff occurs about a month earlier.

Water in the main stem is quite clear with an average turbidity of less than 7 p.p.m. except during high flow periods. Tributaries which enter below Richland are somewhat more turbid, however, and have some effect

on the main river. Water temperatures vary from a low of about 36°F. in February and March to a high of 68°F. in August and September. Tributary streams are slightly warmer with maximum values reaching 75°F.

Dissolved oxygen remains at or near saturation throughout the entire year. Slightly lower concentrations are found in the tributaries, especially during low-flow periods. The pH varies from 7.6 to 8.2 with alkalinity fluctuating from 51 to 81 p.p.m. Corresponding values for the tributaries are somewhat higher. Concentrations of the principal minerals are generally lower than would be important from the standpoint of pollution or toxicity.

Generally speaking, the physical and chemical conditions in both the main stem and the tributaries are well within limits favorable for the support of a good mixed aquatic biota.

Over 90 percent of the plankton in the Columbia River is made up of diatoms. The principal gerera present are *Asterionella. Cyclotella. Fragilaria.* and *Synedra. Asterionella* and *Cyclotella* occur in definite pulses; *Asterionella* is predominant in the spring months, while *Cyclotella* predominates in the late summer and fall months. The tributaries are responsible for the pulses of *Cyclotella.*

Bottom animals consist primarily of clean water forms such as May fly nymphs, midge and caddis fly larvae, and mollusks. Average numbers and weights show little variation between stations with similar hydrographic conditions. The river may be classified as average to rich in fish food organisms (Lagler, 1952). The tributaries contain similar organisms but in somewhat large quantities, with average values about twice those of the main river.

Fish populations of this area consist of both cold and warm water species. The major game and food fish include such migratory species as chinook salmon*(Oncorhynchus tshawytscha),* red or blueback salmon *(Oncorhynchus nerka),* steelhead trout *(Salmo gairdneri,)* and such resident species as bass, white sturgeon *(Acipenser transmontanus).* and mountain whitefish *(Prosopium williamsoni).* Rough and forage fish, such as suckers *(Catostomus* sp.), carp *(Cyprinus carpio),* shiners *(Richardsonius balteatus),* Columbia squawfish *(Ptychocheilus oregonensis).* chiselmouth *(Acrocheilus alutaceus).* and dace *(Rhinichthys* sp.), are abundant. No commercial fishing is carried out in the Priest Rapids-Paterson area, but sport fishing is very popular.

Bass Transplanting Project

The bass transplanting project consisted of catching adult bass from four sloughs near the old townsite of Hanford within the restricted area (S, Figure 1) and moving these fish to the lower Yakima River (R, Figure 1). The fish were measured, weighed, sexed, and marked, and scale sample were taken before they were released.

Participation in this project was limited to members of the Richland Rod and Gun Club who were cleared for entrance into the Hanford area. The fishing was done with sport-fishing gear on Saturdays and Sundays in late April and May when the fish were congregated in slough areas and could be taken readily. As the bass were caught they were retained in wooden vegetable-packing crates, which proved highly satisfactory as live-boxes, until the end of the fishing day. A pickup truck containing a tank with a water-recirculating system was used to transport the bass to the Yakima River. Biologists from the General Electric Company and the Public Health Service supervised the collection of data for age and growth studies.

This project accomplished several purposes: (1) It removed fish from restricted areas into other areas where they would be available for sport fishing; (2) It added brood stock to the Yakima River where the offspring may improve bass fishing; and (3) It provided information on spawning habits, age, growth, and migrations or movements of this resident species.

A summary of catch records for the 1950 to 1953 fishing periods is shown in Table 1. The success of individual fishermen varied considerably, depending on the skill or luck of the individual. The catch per man in a five-hour period ranged from none to as many as 17. Fly and spinner combinations, plugs, and flatfish were equally successful. The catch-per-unit effort and the average size of the fish are considered reasonably good in comparison to other sections of the country (Carlander, 1950). The success of this project in increasing bass populations in the Yakima River is not known, although some fishermen report better catches now than before the project was initiated.

Most of the bass transplanted during this study were marked by clipping a fin. In 1950 the left ventral fin was removed; in 1951 the right ventral; in 1952 the upper portion of the caudal and in 1953 the left ventral. In 1951 the bass were also tagged by attaching a pair of aluminum disks to the back of the fish by means of a nickel-coated pin inserted through the flesh just below the dorsal fin.

The 1951 transplant, when the fish were tagged with metal disks, was the only one in which a concerted effort was made to obtain complete records on the recapture of marked fish. Thirty-five, or almost twenty percent, of these fish were recaptured within a three-month period following their release which indicates a rather intense fishery. Six were caught in May, fourteen in June, and fifteen in July. Almost half of these fish were taken at the mouth of the Yakima River, about ten miles below the point of release. Fifteen were caught in slough areas of the Columbia River—all but two downstream from the mouth of the Yakima River. Only three were caught in the Yakima River near the point of release. Evidently the movement is mostly downstream during this period of high water. However, some of the marked bass returned to the Hanford sloughs

TABLE 1. *Fishing effort and number and size of bass caught during the transplanting project. LM — Largemouth bass; SM — Smallmouth bass. The fisherman day ranged from 5 to 6 hours.*

Fishing period	Fishing effort			Fish caught			Catch per man hour	Catch per man day	Average size	
	Days fished	Man hours	Man days	LM	SM	Total			Total length (inches)	Weight (ounces)
4/29-5/13 1950	5	440	88	8	305	313	0.75	3.5	15	36
4/8-5/6 1951	8	519	104	49	180	229	0.44	2.2	15.5	40
4/4-5/3 1952	4	270	57	13	211	224	0.82	4.0	15.7	40
4/4-5/9 1953	7	642	107	17	174	191	0.30	1.8	16	42

and were recaptured in subsequent years, which indicates a definite upstream movement which probably occurs during low water periods later in the year.

These reports of marked fish indicate that bass may move for considerable distances up or downstream but with no set distribution pattern. Marked fish were taken from many different areas, mostly downstream in the Yakima River from the point of release and in the Columbia River both upstream and downstream from the mouth of the Yakima. Some were taken over forty miles from the point of release. A fairly large percentage of marked bass returned to areas from which they were first captured. Almost eleven percent of the fish taken in 1953 were ones that had been previously taken and marked in the same areas, and had been transported and released in the Yakima. This does not necessarily indicate a definite homing or migratory instinct, but rather that these fish do move extensively and may simply wander back into the preferred habitats. The recapture of such a large percentage of the bass would indicate a low population in the Hanford area.

The disk tag was generally unsatisfactory for these bass. Even though a number of tags were returned within a few months after release, most of the tagged fish were in poor condition and had partially healed or open sores on their backs. No tags were found intact the following season, but a few fish were found with scars indicating they had been tagged. The clipped-fin marks were considered successful for a period of about three years, but after this time regeneration of the fins obliterated the mark. Apparently this kind of mark is easily overlooked by the average fisherman, and many clipped fins were not seen even by fishermen participating in the transplanting although they had been alerted to watch for them.

Spawning Observations

Limited observations during the spring and summer seasons of 1951 and 1953 gave the following indications concerning the spawning of smallmouth bass in the Columbia River and tributaries. Large numbers of adult bass moved into the slough areas generally in April and May, just prior to the advent of high water. Some of these sloughs were land-locked during low-water periods and bass remained in them from the previous year; others were connected to the main river at one end, but consisted mostly of backwater. The water in these sloughs warmed up much faster than that in the main channel. Most of the fish which moved into the sloughs were sexually mature and began building nests for spawning. The water temperature in the spawning areas was generally between 55° to 60°F. when spawning activity was observed, as contrasted to a temperature of 45° to 50°F. in the main river channel at this time.

Early spawning was generally unsuccessful. Eggs were observed in late April on several occasions, but no fry were found during this early period. As the river began its annual rise, colder water began passing through the

sloughs and the adults seemingly abandoned their nests. Twelve large nests which contained eggs and which were actively attended by adult bass were observed in one section of a slough on April 26. The water temperature near the nests was 61 F. and no water was passing through this slough, although it was connected to the main river at the lower end. One week later (May 3) observations were again made on these nests. The river level had risen approximately ten inches. Water was entering the slough at the upper end and running through at a fairly slow rate, and water temperature had dropped to 54 F. No bass were observed in attendance at the nests and, on closer examination, eggs in all of the nests were observed to be coated with fungus. It is believed that the colder water caused the bass to abandon these nests before the eggs hatched. Higher water precluded a further examination of these nests, but no fry were observed anywhere in the vicinity for the next several weeks.

The only successful hatching of fry in the Hanford sloughs was observed much later, during the period July 15 to August 1, after the river level had dropped somewhat from the peak and water temperatures in the sloughs ranged from 60 to 75°F. Schools of black fry, which had just risen from nests, were observed in several slough areas in 1951 and 1952. The fry appeared to dissipate rapidly and few could be found a day or two later.

The number of eggs in individual nests and the number of fry hatched compared favorably with observations previously made in bass streams of the East. The fry and fingerlings captured appeared normal in every respect, indicating that there were no adverse effects from effluents of the nuclear reactors.

The over-all success of bass spawning in the Hanford areas was very poor. This was attributed principally to fluctuating water stages and temperatures during the spawning season. Poor survival of the fry that did hatch was attributed to the large numbers of predatory squawfish and other rough species. Unsatisfactory reproduction was also indicated by the paucity of young bass taken by fishermen during the transplanting project or caught in seines used to collect samples for studies on effects of the reactor effluent.

Some successful spawning of bass occurred in the lower Yakima River. A few schools of newly-hatched black fry were observed in early July when the water temperature was 66°F. Young-of-the-year fingerlings were seined in this area, as well as in the Richland, Kennewick-Pasco, McNary, and Paterson areas of the Columbia River (Figure 1). It is believed that many of the bass caught in the Hanford slough areas may have been produced in lower sections of the Columbia River or in tributaries, and gradually moved into these sloughs.

Age and Growth

Age and growth studies were made on 225 smallmouth bass taken from the Hanford area. Most of these fish were those obtained during the

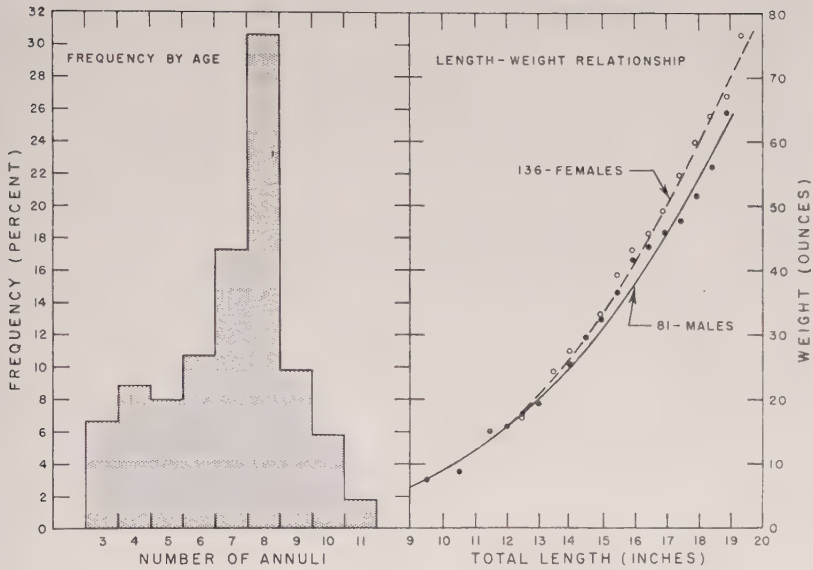

FIGURE 2.—Frequency of occurrence of the different age groups and the length-weight relationships of 225 smallmouth black bass taken from the Columbia River during 1952.

transplanting project in April and May, 1952. Data on weight, total length, and sex were obtained immediately upon capture. Most of these fish were ripe, and sex could be determined readily by the general appearance of the fish and the shape near the vent. Some other fish included in this study were taken during September and Ocober, 1952, by means of 3-inch mesh gill nets, 150 feet long. As these were dissected for determination of radioactivity, the sex was ascertained from internal examination.

Age determinations were made by mounting the scales in a glycerine-gelatine media, (Lagler, 1952) and projecting their image on a screen by means of a prism mounted on a monocular microscope equipped with appropriate eyepieces and objectives. The number of annuli were counted directly. The annulus formation was very distinct on most of the scales and there was a surprisingly small number of regenerated scales.

The frequency of the various age groups and the length-weight relationship is shown in Figure 2. Scales from almost half of the fish had seven or eight annuli which indicated that these bass were beginning their eighth or ninth growing season. None of the scales examined had less than three annuli, and several large fish had eleven or more. The spacing of the annuli indicated that most of the growth of bass occurred during

the period from July to October.

The weight of Columbia River smallmouth bass in relation to total length was slightly greater, especially in the larger fish, than that reported in studies from some other areas (Carlander, 1950).

Females were heavier than males, probably because most of them were taken when they were heavy with eggs. Very little difference in the length-weight ratio between males and females was noted for about twenty bass taken in gill nets after the spawning season. Most of the larger fish taken were females, however.

Of the 219 smallmouth bass taken in April and May, 1952, 90 were judged to be males and 129 females. Of the twenty-two fish taken in gill nets in September and Ocober, dissection showed that eight were males and fourteen females. In 1953, the catch was composed of 64 males and 109 females. This apparent predominance of the females may have been due to selective methods of capture. The females were generally larger, with an average total length of 16.3 inches and weight of 44 ounces; the

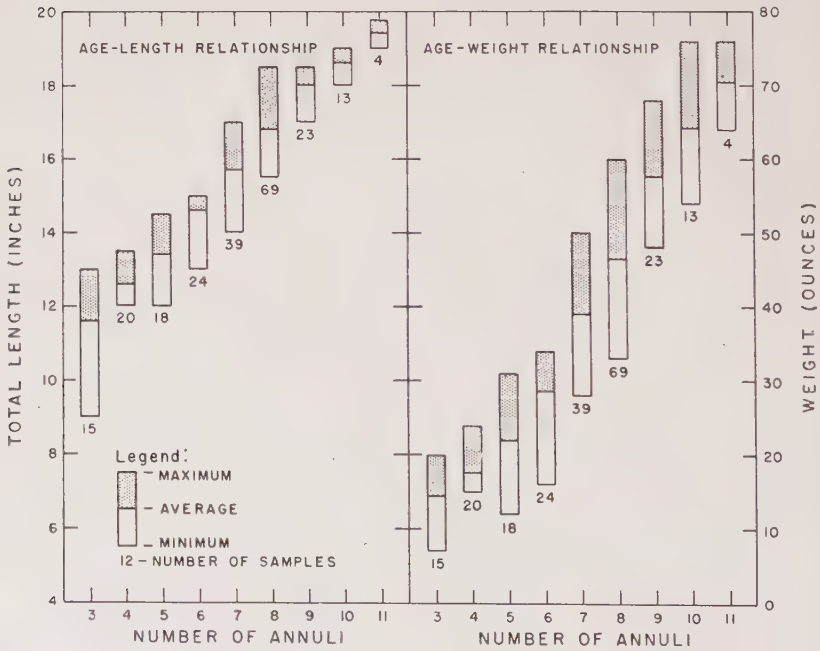

FIGURE 3.—Range in total length and weight in each age group of 225 smallmouth bass taken from the Columbia River during 1952.

males averaged 14.9 inches in length and 33 ounces in weight. The average bass, 15.7 inches long and 40 ounces in weight, was larger than those generally taken from most bass waters in other parts of the country.

The average size of bass caught in the Yakima River was more on the order of what might be expected from typical small mouth bass streams of the East. The length of eleven males and six females caught in July of 1952 ranged from 10 to 17½ inches, with an average of 13 inches, and their weights ranged from 8 to 44 ounces with an average of 20 ounces.

The range in total length and weight of bass of different age groups is shown in Figure 3. Considerable variation occurred in both length and weight among bass of the same age. An individual fish of a particular length or weight could possibly fall into as many as three age groups. The size of the average fish increased quite uniformly with age, however. Growth rates of smallmouth bass in this section of the Columbia River appear quite rapid in comparison with those reported for this species in many other sections of the United States and Canada (Carlander, 1950). Faster growth has been found in only a few localities, and mostly in lakes. This is surprising since the maximum temperature in the main Columbia River is about 68 F., far below the temperature generally considered optimum for the growth of this species. Most of the bass were found near slough areas which were somewhat warmer, however. Large numbers of bass were observed in the main river during September and October when water temperature was at its maximum, but they evidently remained in the sloughs most of the year. The abundance of bottom organisms and the extremely large numbers of forage species of fish such as shiners, chubs *(Mylochelius caurinus)*, squawfish, sculpins *(Cottus* sp.), dace, and suckers provide an excellent food supply. This, coupled with the poor spawning success and the lack of competitive spiny-rayed species, may account for the rapid growth rates.

Fifteen largemouth bass were taken during April and May, 1952. There were eight males and seven females which ranged from 10½ to 19 inches in length and from 9 to 64 ounces in weight. The average length of 15½ inches and weight of 38 ounces was quite similar to that of smallmouth bass. Scales from these fish had from three to ten annuli and growth rates were similar to the smallmouth. The compartively cold water of the Columbia River evidently affected the growth of largemouth bass, since, under favorable conditions, it is generally considered a much faster growing species than the smallmouth.

Effects of the Radioactive Effluent

Columbia River water is used to cool the Hanford reactors. Certain elements present in the cooling water as dissolved solids are made radioactive when exposed to the neutrons in the reactor. Most of the radioactive isotopes which are formed have very short half-lives, but some persist in

the effluent discharged back into the river. A few of the isotopes accumulate in Columbia River organisms. This concentration of radioactive materials by the aquatic forms has been reported by Davis, *et al.* (1952), Robeck, Henderson, and Palange (1954), Foster and Rostenbach (1954), Foster and Davis (1956), and Henderson, Robeck, and Palange (1956).

The concentration of radioactive materials in smallmouth bass collected in the vicinity of Hanford in 1952 by the U. S. Public Health Service is shown in Table 2. Determinations were made on individual tissues of the fish and the values for parts which were of similar magnitude—i.e., skin and muscle, scales and bone, and all internal organs (liver, sex organs, kidney)—are combined in the table. The methods used to make these analyses are described by Robeck *et al.* (1954).

TABLE 2.—*Concentration of radioactive materials in smallmouth bass in the Hanford vicinity during 1952.*

Month	Number of fish	Range in gross beta activity in units 10^5 microcuries per gram of original tissue			
		Skin and muscle	Scales and bone	Internal organs	Stomach contents
April	11	1-16	1-4	1-8	2-1600
July	4	18-64	120-450	72-420	260-450
September	5	63-250	310-3520	98-840	700-8240
October	9	38-220	290-2260	170-780	530-2800
November	4	12-100	87-415	27-210	No contents
December	1	10-26	75-82	50-320	No contents

Radioactive materials were concentrated in all parts of the bass. However, the concentration was about ten times higher in scales and bone than in skin and muscle, the edible parts. Levels in internal organs were intermediate while stomach contents were generally higher than any of the tissues. The variations in concentration of radioisotopes in the parts from different fish caught at the same time were quite large, and probably resulted from movements of the bass in and out of slough areas which contained less radioactivity than the main river. The levels were definitely correlated with those of stomach contents or food. The principal radioisotope concentrated in the bass, and in other aquatic animals as well, was radiophosphorus (half-life 14.3 days). This accounts for the greater radioactivity in the bone and scales since these structures are comparatively rich in phosphorus. Although P^{32} made up less than one percent of the activity in the water, it was responsible for over 90 percent of the activity in the fish. This represents a concentration of many thousand fold for this particular isotope in the fish over the level in the water.

The seasonal variation in the concentration of radioisotopes in the water, in bass, and in some of the food organisms is shown in Figure 4, along

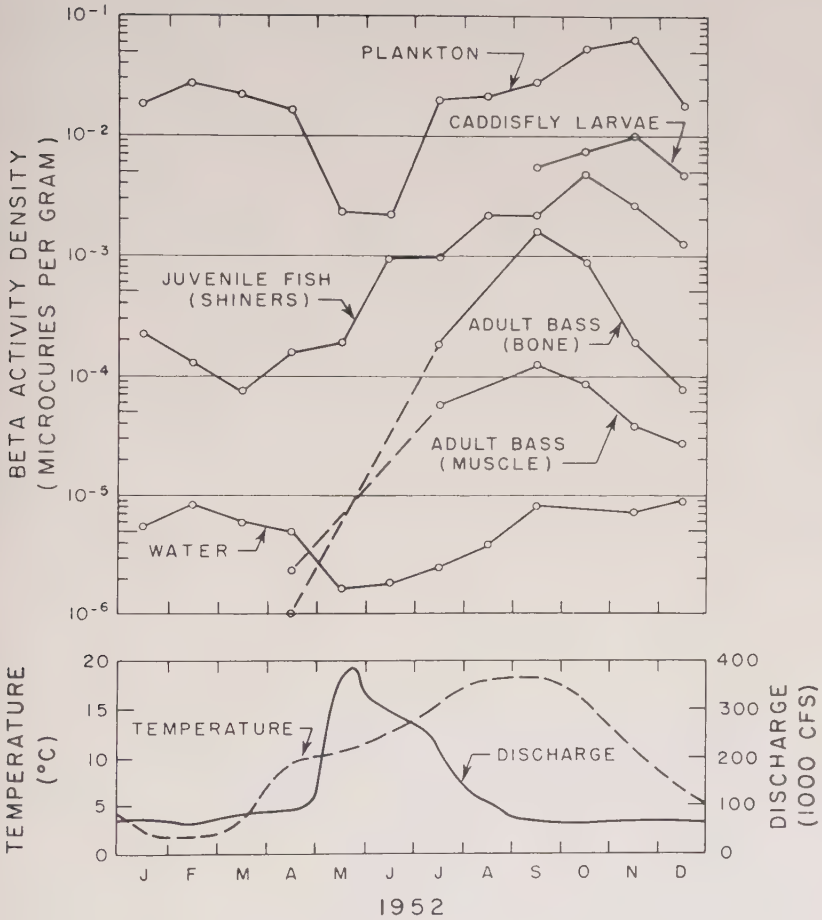

FIGURE 4.—Seasonal variation in average concentration of beta emitters in smallmouth bass, food organisms and water in the Columbia River during 1952. River discharge and temperature are shown for comparison. Background activity for Columbia River water is about 1×10^{-8} microcuries per milliliter and for organisms is about 1×10^{-6} microcuries per gram.

with river discharge and water temperature. The variations in the level of radioactivity in the water were due primarily to dilution at the time of the freshet and to fluctuations in discharge rate of the effluent. The concentration of isotopes in the bass did not follow that of the water but was related to temperature and to the radioactivity of the food organisms. Metabolic rate (which is dependent upon water temperature) is primarily responsible for the wide seasonal variations in the concentration of isotopes in the aquatic animals (Davis *et al.,* 1952; Foster and Davis, 1956; and Henderson *et al.,* 1956).

It was apparent that most of the radioactive materials present in bass and other fish were assimilated from food organisms rather than by direct absorption from the water. In April, activity levels in the bass were near background; this would indicate that these fish had taken little or no food for some time. The levels rose rapidly with increasing water temperatures, even though the freshet stage of the river greatly reduced the concentration of isotopes in the water. A maximum was reached in September when temperature was highest and when river flow had returned to normal. Radioactivity in the fish diminished rapidly with decreasing water temperatures during November and December, even though river flow was low and thus the concentration of effluent in the river was greatest. A similar pattern was followed by food organisms of the bass except that their level of radioactivity remained considerably above background during the winter months. This indicates that although the feeding rate of the prey species was materially reduced during the cold months, these forms continued to ingest some radioactive material.

The concentration of radioisotopes in bass was less than that in the food organisms and less than that of nonpiscivorous fish. There is a general decrease in the level of radioactivity along the food chain. Phytoplankton, which absorb nutrients directly from the water, concentrate the largest amounts. Next in order are the herbivoruos insect larvae, and then juvenile fish which feed on the bottom organisms. Adult bass, which are at the end of the food chain, are least radioactive.

The studies of the U. S. Public Health Service and of the General Electric Company detected no adverse effect on fish or their food organisms from the discharge of reactor effluent into the Columbia River. The quantities of radioactive materials contained in the bass were well below amounts which would be hazardous to persons who might eat them or to the fish themselves. The radioisotopes which concentrated in the fish had short half-lives, which precluded any buildup from year to year. However, the fact that fish, including bass, may concentrate some isotopes to many times the level present in the surrounding water points up the necessity for considering such concentration in establishing safe operating practices for atomic energy installations.

Acknowledgments

The authors are sincerely grateful to the officers and members of the Richland Rod and Gun Club whose desire to initiate and carry out a project for the improvement of bass fishing made possible the collection of much of this data. We are likewise grateful to the security officers of the Atomic Energy Commission and the General Electric Company for their cooperation and guidance in carrying out the special fishing within the restricted areas. We wish to thank the Washington State Department of Game for their encouragement and assistance, and for the tags which were attached to the bass. Especially, we would like to thank the local Game Protector, Mr. Mitchell Kershaw, for his many suggestions and for his persistent efforts in locating and reporting marked bass which had been recaptured. We are also indebted to the biologists of the General Electric Company and of the U. S. Public Health Service who helped in measuring the bass and rendered professional assistance in many ways.

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MOVEMENTS OF TAGGED WHITEFISH IN NORTHERN LAKE HURON AND GEORGIAN BAY

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Abstract

Recapture pattern of whitefish tagged in South Bay, northern Lake Huron, suggests a major migration route east along the south shore of Manitoulin Island into Georgian Bay. Tagged whitefish leave South Bay in early summer, spend the remainder of the year outside and return again the following spring. No fish tagged in Georgian Bay were recaptured outside that body of water. Tagging seems to indicate two discreet populations. Study is based on recaptures from 5,901 tagged whitefish of legal and sub-legal size (14-20 inches fork length) during the years 1949-1953.

Introduction

The common whitefish, *Coregonus clupeaformis* Mitchill, is an important commercial species in the northern Lake Huron-Georgian Bay area. Since 1949 a tagging experiment has been carried on at the South Bay Fisheries Station of the Department of Lands and Forests. A study of the movements of whitefish in the area constituted one phase of the tagging program. This report covers the period 1949-1953.

In 1947 the Ontario Department of Lands and Forests in cooperation with the Ontario Federation of Commercial Fishermen initiated an experimental fishery in South Bay, an arm of Lake Huron extending into the south shore of Manitoulin Island. South Bay has a surface area of approximately 20,000 acres and is connected to Lake Huron proper by a narrows 240 yards wide. Preliminary studies pointed out the great need for information on the stocks of fish being exploited by the experimental fishery. Pound net fishing in 1947 and 1948 showed a large population of whitefish present in South Bay in May, June and early July. These fish could not be taken in numbers either in pound or gill nets after July 15. In order to gain further information on this spring population of whitefish a tagging program was started in 1949.

Methods

Fish were available for tagging from an experimental pound and trap-net fishery. Streamer type plastic tags were used, and were attached through the anterior base of the dorsal fin by means of mono-

filament nylon. An attempt was made to anchor the tag behind the base of the first dorsal fin ray. No detailed study of tag loss was made. The same tag used on lake trout indicated a loss of 10 percent per year (Fry, 1952). It is thought that tag loss in whitefish is of the same general order. Red, green and yellow tags were used during the course of tagging. Observations made in South Bay and opinions expressed by commercial fishermen indicate that the yellow tags are most easily seen, especially if the fish are taken in pound or trap nets. The fish were lightly anaesthetized with five percent urethane solution before tagging and were released immediately.

Tags were recovered both from the South Bay experimental fishery and from the adjacent Lake Huron-Georgian Bay commercial fishery. A letter describing the tagging was sent to each commercial fishing license holder and a reward was paid for the return of tags. Cooperation from the commercial fishermen has been excellent.

In 1949 and 1950 tagging was largely confined to fish taken in South Bay. By 1951 however, the need for tagging fish outside South Bay became apparent, and each year since 1951 some of the whitefish taken in commercial pound nets have been tagged in Georgian Bay. A smaller number was tagged in Lake Huron in 1951 and 1953. In all 4,383 whitefish were tagged and released in South Bay. In addition, 1,518 fish were tagged and released in Lake Huron and Georgian Bay.

Recovery of Tags from South Bay Tagging

The recovery of tags has shown that South Bay whitefish range rather widely. This is in contrast to what was found for the South Bay lake trout and smallmouth bass populations (Fry 1952, Fraser 1954). Both these species formed local populations that remained in South Bay. Smith and Van Oosten (1939) working with tagged lake trout and whitefish in Lake Michigan found the opposite to be true; lake trout moved extensively and it was concluded that the whitefish were non-migratory. It seems likely that local hydrographic conditions are a major factor in determining the movements of the same species in different areas. Whitefish tagged in South Bay have been recaptured at scattered points in Lake Huron and the North Channel, but by far the largest number have been taken in Georgian Bay.

Since 1950 there has been a shift in the distribution of fishing effort from Lake Huron to Georgian Bay. Production of whitefish in Georgian Bay rose from 805,000 pounds in 1949 to more than 6 million pounds in 1953. This shift in fishing effort has had an undetermined effect on the recovery of tags; very few tags have been returned from Lake Huron since 1950.

Figure 1 shows the locations where whitefish tagged in South Bay have been recaptured. The maximum distance travelled was 150 miles, and

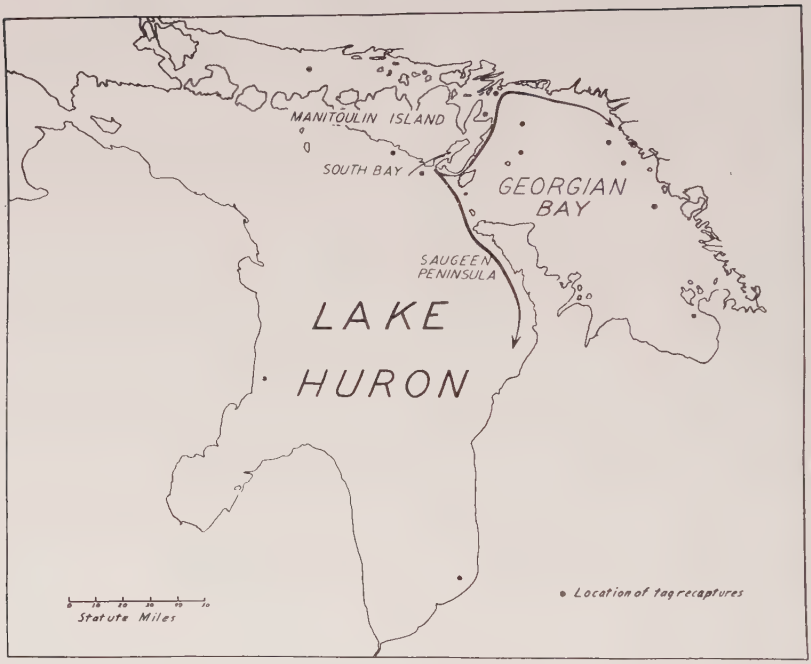

FIGURE 1.—Apparent migration routes and locations of recaptures of whitefish tagged in South Bay.

that by a single fish taken off Grand Bend in southern Lake Huron one year after tagging. Three tags have been returned by an American trap-netter fishing off Oscoda, Michigan. Two of these tagged fish were taken the same year they were tagged and the other, two years after tagging. Three tags have been reported from the North Channel west of Little Current. All other returns have come from various points along what seem to be two well-defined migration routes. These migration routes are indicated by broad arrows on Figure 1. The first of these routes is along the islands that bar the entrance to Georgian Bay, thence south along the west shore of the Saugeen Peninsula, as far as Southampton. This route was most evident in 1950, the last year when sufficient fishing was done in Lake Huron to provide reliable information. Thirty-seven or 12 percent of the total outside recaptures for that year were taken along the Saugeen shore.

By far the greatest number of recaptures have come from two pound net fisheries operating along the east shore of Manitoulin Island and the west shore of Fitzwilliam Island. Each year since 1949 more than 50 percent of the total recaptures have come from these pound nets.

This recapture pattern indicates a major movement from South Bay east along the south shore of Manitoulin through Owen Channel into Georgian Bay. During these years fish tagged in South Bay began to appear in the Owen Channel nets after the middle of June, reached a peak about July 15, and thereafter were taken as scattered individuals until the pound nets were removed in late September or October.

Throughout the summer and until the close of the fishing season in November, tagged fish were taken along the north and east shore of Georgian Bay. A few were taken as far south as Parry Sound and a single tag has been returned from Thunder Beach in the extreme southern end of Georgian Bay. The Britt Area in the northeast corner of Georgian Bay, however, seems to be the most distant point reached by most of the South Bay fish that enter Georgian Bay. This is a major spawning area. No tagged fish have been taken along the east shore of the Saugeen peninsula.

Recaptures in South Bay the spring following tagging suggest that the South Bay whitefish population retains its identity and returns to South Bay. In three instances fish tagged in South Bay were recaptured and released in Georgian Bay the same summer, then recaptured in South Bay again the following spring.

Table 1 summarizes the tagging data for the years 1949-1953. Percentages are based on the maximum number of tags extant at the beginning of each year. Almost all fish recaptured in the nets of the South Bay experimental fishery were released. Some of the fish were subsequently recaptured in commercial gear and killed. No allowance has been made for tag loss or for unreported tags.

Percentages of tagged fish recaptured in South Bay during and immediately following tagging ranged from 12.5 percent in 1953 to 24.0 percent in 1951. A possible explanation for the lower recovery rate here in 1953 is that the tagging was done late in the season and most of the fish probably left South Bay shortly after they were tagged.

Recaptures during the year "y," the year of tagging, by commercial fishermen fishing outside South Bay, ranged from a low of 7.7 percent in 1952 to a high of 14.4 percent in 1953. These figures indicate a rather intensive commercial fishery operates in the area.

Percentage recaptures in the year following tagging (y plus 1) both in South Bay and by the commercial fishery approximate those taken outside South Bay the first summer, being approximately 10 percent of the tags extant. Also the percentages of the tagged population taken in South Bay and outside South Bay are very nearly equal. This would suggest that either half of the tagged fish remain in South Bay or that those that left in July return sometime before the next fishing season. The second suggestion is most tenable and is substantiated by direct evidence. The percentage of tagged fish recaptured in the second year after tagging, (y plus 2) is much lower than would be expected on the

TABLE 1.—*Recaptures of whitefish tagged in South Bay, Ontario. Percentages are based on maximum possible number of tags extant at the beginning of each year. Figures in parenthesis are percentages including multiple recaptures.*

Year recaptured	Y (year of tagging)		Y plus 1		Y plus 2		Y plus 3		Y plus 4		Number tagged
	S. Bay	Outside	S. Bay	Outside	S. Bay	Outside	S. Bay	Outside	S. Bay	Outside	
1949	14.9 (23.8)	8.6	6.7	5.7	1.7	1.7	0.5	1.1	0.0	0.0	428
1950	13.8 (24.8)	12.7	10.4	10.1	2.3	2.2	0.2	0.3	—	—	2442
1951	24.0 (30.6)	9.4	10.7	9.9	1.9	1.2	—	—	—	—	987
1952	15.4 (26.9)	7.7	3.9	7.9	—	—	—	—	—	—	438
1953	12.5	14.4	—	—	—	—	—	—	—	—	125
All years											4383

basis of percentage recaptured in year, y plus 1, being about 2 percent of the maximum number extant. Even if a 10 percent tag loss is assumed, returns for year, y plus 2, do not approach those obtained in year, y plus 1. It is probable that natural mortality especially lamprey predation, combined with tag loss was responsible for the decrease in tag returns in years, y plus 2. The returns for the three y plus 2 years for which data are available show almost identical recapture rates in South Bay and outside South Bay. This is a strong indication that the tagged fish form a discrete population that they return each spring to the area where they were tagged. If this were not the case one would expect that in following years more of the fish would be recaptured outside South Bay.

Tag returns for year y plus 3 average less than 1 percent and no returns have come from fish tagged longer than three years.

Recovery of Tags from Lake Huron and Georgian Bay Tagging

Tag recoveries from whitefish tagged in Lake Huron and Georgian Bay present a somewhat different picture than recoveries from South Bay. No well-defined migration routes have been observed. There is, however, a general tendency for the fish to move in a northeasterly direction. The longest distance travelled by a Georgian Bay whitefish was about 75 miles from the Mink Islands off Parry Sound to Fitzwilliam Island on the west shore of Georgian Bay. Most of the recaptures have come from pound nets fished along the east shore of Manitoulin Island and in the Killarney area. This was the area where most of the fish were tagged.

It is of interest that none of the whitefish tagged in Georgian Bay have been recaptured in South Bay even though some of the tagging was done when fish with South Bay tags were being taken in the same pound nets. The only fish tagged elsewhere that were recaptured in South Bay were from Thomas' Bay, a bay about five miles

Table 2.—*Recaptures of whitefish tagged in Lake Huron and Georgian Bay*[1] *Percentages are based on maximum possible number of tags extant at the beginning of each year*

Year recaptured	Y (year of tagging)		Y plus 1		Y plus 2		Number tagged
	S. Bay	Outside	S. Bay	Outside	S. Bay	Outside	
1951	0.3	8.1	1.8	12.8	0.4	3.4	765
1952	0.0	12.4	0.0	22.2			336
1953	0.0	23.4					378

[1]All fish recaptured in South Bay were tagged in Thomas Bay in 1951.

east of the entrance to South Bay. Some fish were taken but the proportion of recoveries in South Bay was less than that for fish tagged in South Bay. This would seem to be further evidence for a discrete South Bay population. How these local aggregations of fish in a large lake are maintained is one of the fascinating problems of ecological research.

Table 2. summarizes tagging and recapture data for fish tagged outside South Bay. Recapture percentages tend to be somewhat higher than for South Bay tags, but are of the same general order. It is probable that an increase in fishing effort in Georgian Bay was responsible for the higher rate of recapture of fish tagged outside of South Bay.

An additional piece of information that is at present unexplainable is that there is a difference in distribution of the recaptures from the two types of gear used in the whitefish fishery. Eighty-two percent of the total number of recaptures both of South Bay and Georgian Bay tags were taken in pound nets. It is estimated that pound nets take slightly less than 50 percent of the total Georgian Bay whitefish catch. No correlation between the size of the fish and the likelihood of being taken in a particular type of gear could be found.

Acknowledgments

This work was carried out under the direction of and with encouragement from Dr. F. E. J. Fry, the Director of the South Bay Fisheries Station. A number of persons helped with the tagging, especially Messrs. J. M. Fraser, K. K. Irizawa, D. Cucin and W. I. Chapman. Thanks are due to these men and to all of the South Bay staff. The work was made possible by the cooperation of all of the fishermen who kept records and turned in tags. Especial thanks are due Messrs. Joseph and Julian Low, William and Cecil Low, Arthur Jackman, Basil D. Roque and Charles and Peter Lowe, all of Killarney, Ontario, Mr. Nathan Doran of Sauble Beach, Ontario and Mr. Oliver Franklin. These men made the tagging possible by allowing a tagging crew aboard their boats.

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EXPERIMENTAL SPIRAL RACEWAY FOR TROUT

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Most conventional raceways for rearing trout are built with straight parallel concrete walls and, in Wisconsin, such raceways have a concrete floor with a slight slope and associated water and sewer facilities. We have designed and now have in operation an experimental model raceway of a spiral type. Essentially it is a single-wall raceway with the wall curved in a spiral.

Such a raceway from the engineering point of view has several advantages. There is a substantial saving in construction costs because of elimination of one concrete wall. Both sides of wall form sides of the raceway. Such a raceway is compact and requires less space than a conventional raceway of similar length. Water sewer lines and air lines, with which we are experimentally trying to aerate the water, are required in about 25 percent the amount needed in a raceway of the usual type.

In an area with cold winters, such as Wisconsin, frost damage to concrete raceway walls is an ever-present problem. In the spiral raceway the area of wall exposed to frost is reduced and thereby a longer useful life of the structure is probable. Another engineering advantage is that the water input is at the center of the spiral which is raised to provide the necessary fall in the raceway. The compact nature of the spiral raceway makes a combination of a head of water a long gradually sloping area for conventional raceways unnecessary. Any area lower than the water supply can be used.

With use of a center post in the middle of the spiral a pivoted catwalk can make any part of the raceway available. Similar on over-head hoist for handling fish, food and equipment can be pivoted to the center post. The spiral design lends itself easily to expansion by adding an additional spiral to the outside of the raceway. The compact design has prospects for use of automatic feeders and it is easily covered to protect the trout. A 1-to-10 scale model has been in operation for several months. It represents a raceway 5.5 feet wide, 385 long enclosed by a 6-inch concrete wall and with diameter across the spiral of 53.3 feet. On more turn around the spiral, at operational size, would supply 165 feet of additional raceway. Experimental adjustment of water flow in the model shows that it can be made self-cleaning by laying a perforated pipe along the inner edge of the spiral.

Biological aspects of the spiral raceway remain to be tested but the prospects are such that two operational raceways of this type are now planned for Wisconsin trout rearing.

SCIENTIFIC FISH CULTURE IN QUEBEC SINCE 1945

LOUIS-ROCH SEGUIN

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ABSTRACT

In Quebec, a number of experiments have been undertaken to improve the quality of the trout reared for planting purposes. Data are presented on efficiency of diets and effects of light and temperature on reproduction, incubation, growth and survival of brook trout *(Salvelinus fontinalis)*, lake trout *(Salvelinus namaycush)*, Quebec red trout *(Salvelinus alpinus marstoni)*, rainbow trout *(Salmo gairdneri)*, brown trout *(Salmo trutta)* and Atlantic salmon *(Salmo salar)* and on hybrids between these species, especially the brook-lake trout hybrid (splake).

INTRODUCTION

Fish culture is not a cure-all for fishery problems but it is a powerful and useful instrument. In Quebec, in addition to routine plantings, hatcheries supply fish for stocking virgin lakes or lakes cleared of fish by poisoning and they also supply yearling trout or salmon to fishing associations for rearing another year in natural or semi-artificial ponds before release into regular fishing waters. In the more densely populated regions of the Province this type of pond-rearing of trout and salmon is becoming increasingly popular. It is the job of fisheries biologists to find methods for raising sound, vigorous fish at lowest possible cost; and for this reason research work in trout and salmon rearing has long been pursued in the hatcheries of the Quebec Department of Fish and Game. The results of some of our experiments in trout rearing during the past ten years are summarized in the following paragraphs.

TROUT DIETS

By a series of experiments undertaken by Bouthillier[1] it was found that iodine given as a food supplement promoted brook trout growth and that the further addition of a salt mixture, already described by Jones and Foster (1942), to the assay diets improved their nutritive quality very little if at all.

[1]Bouthillier, L.P. The influence of various diets on trout growth. Typewritten Report, Quebec Biological Bureau, University of Montreal, P.Q. 1945.

Seguin and Legendre (1950) and Seguin (1954) report many experiments on the artificial feeding of brook trout. Lagueux and Gagnon[2] in 1953 repeated several of these experiments with Atlantic salmon fingerlings. Many ingredients were included in these experimental diets: beef liver, horse liver, cod liver, pork spleen, fish flesh (sucker), steamed horse blood pudding, dried skim milk, fish meal, lobster shell meal, animal liver meal, meat meal, cod liver meal, fishflake, corn gluten meal, soya bean meal, dried brewers' yeast, wheat bran, kelp meal, alfalfa meal, dried grass meal, dried brewers grains, granulated soymeal, wheat germ, shorts, riboflavin, cod liver oil, ground limestone, manganese sulphate, common salt.

Following are conclusions of general interest reached in experiments with artificial diets.

1. Meat diets are generally the best, beef liver best of all those tested.
2. Meat meal diets also give excellent results.
3. Addition of fish flesh (sucker) did not improve the diet.
4. Whole cod liver, substituting for other meat, helped the growth of the fish for some time but eventually was harmful to their health.
5. Addition of steamed horse blood pudding did not improve any diet and when given alone was fatal to the fish.
6. It was found that, during the first year, addition of 1 to 10 percent of lobster shell meal to a beef liver diet increased brook trout fingerlings growth, improved their health (98.6 percent survival has been obtained) and lowered the feeding coefficient (a conversion factor as low as 1.45)[3].
7. In contrast to the results of Bouthillier[1] who in 1945 succeeded in coloring the fins of brook trout by feeding shrimp meal, no coloration resulted, either of skin or flesh, from feeding to brook trout fingerlings and yearlings, during one year, as much as fifty percent of lobster shell meal with a beef liver diet.[3]
8. Abrupt transition from one diet to another slowed down growth temporarily and produced in the growth curve a plateau-like leveling off. When it is necessary to change a diet, it seems advisable to accustom the fish gradually to the new diet.
9. It was found advantageous to add enough water to dry food mixture to enable the fish to eat it as quickly as possible. However, a food that is too soft may result in waste by breaking up and dissolving the food elements in the water.

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[2]Lagueux. R., and A. Gagnon. Rapport d'experiences sur l'alimentation du saumon *(Salmo salar salar)* a la Station piscicole de Tadoussac. Typewritten Report, Quebec Biological Bureau, University of Montreal, P.Q., 1953.

[3]Seguin, L.R. L'utilisation de la farine de carapace de homard dans l'alimentation artificielle de la truite mouchetee *(Salvelinus fontinalis)*. Typewritten Report presented at the 24th annual meeting of the Acfas, University of Montreal, P.Q., 1956.

10. The most promising diet was that which includes meal in pellet form (Seguin, 1953a and 1953b). As is shown in Table 1, the same dry food mixture when given in pellet form was better than in meal form, probably because, when properly fed, the food elements in the pellets were entirely eaten by the trout before they began to dissolve in the water.

11. Pellets of the composition described in Table 1 have also been tried as food for brook trout spawners. The criterion of success is the quality of eggs and larvae, expressed as percentage survival. During each of these experiments the rate of mortality of the spawners has been insignificant, but the quality of eggs varied according to the amount of pellets given. Feeding liver only once a month (or even once a week) and pellets all the other days resulted in high mortality of eggs during incubation and among the newly hatched larvae. But feeding pellets one day and liver or spleen the next gave very good results.

For instance, for one year, four groups of 2.5-year-old brook trout spawners were fed respectively the following diets: (A)—Spleen every day; (B)—liver every day; (C)—liver one day and pellets the next and (D)—spleen one day and pellets the next. Survival of larvae after yolksac absorption was 56 percent for group (A), 65 for (B), 67 for (C) and 73 percent for group (D).

TABLE 1.—*Efficiency and cost of three brook trout fingerling diets*[1]

Diet composition in parts by weight	Mortality percentage	Growth rate[2]	Conversion factor	Cost of food per pound of trout
Beef liver 100	0.4	484	2.55	$0.64
Liver 66 + meal[3] 34	3.3	283	2.34	0.41
Liver 66 + pellets[3] 34	2.0	575	1.86	0.35

[1]The experiments were conducted for a period of three months (August 10 to November 15, 1951). The average weight of the fingerling at the beginning of the tests was 5.5 grams. The daily amount of food given has been calculated in accordance with the Deuel *et al.* (1952) feeding chart. Water temperatures were from 41° to 62°F.

[2]Growth rate is expressed as percentage gain which is calculated by dividing the gain in weight at the end of the experiment by the weight of fish at the start of the experiment and multiplying the result by 100.

[3]Diet composition by weight of meal and pellets is the same: dried skim milk, dried brewers yeast, dried brewers grains and wheat germ 5 parts each; fish meal 10 parts; meat meal 20 parts; soya bean meal 27.5 parts; alfalfa meal 7.5 parts; common salt and shorts 2.5 parts each; riboflavin 3.4 parts; cod liver oil 0.4 part; ground limestone 6.1 parts; and manganese sulphate 0.1 part.

Effect of Light and Temperature on Incubation, Growth and Spawning of Trout

It is general knowledge among fisheries workers that the warmer the water, up to an optimum temperature, the shorter the period of incubation. This is demonstrated for five species of salmonids in Table 2. Warmer water temperatures also resulted in more rapid growth of the fish. Seguin (1951), by keeping the eggs and fish in warmer water than usual, (50 to 61°F.) obtained, 12 to 22 months after the extraction and fertilization of the eggs, brook trout averaging 5 to 15 times heavier than those reared under usual hatchery conditions (43 to 52°F.) Because water was warmed to 50 to 61°F., eggs of brook trout fertilized on November 7, 1948 produced by November 12, 1949, 174-gram fingerlings instead of 12-gram fish of the same age in water of 43 to 52°F. Similarly, yearlings of this same hatch on September 5, 1950, weighed 425 grams when raised in the warmer water in contrast to 86 grams for trout raised in the colder water.

Because it is likely that optimum temperatures are not the same for all species of trouts and salmons, a series of experiments was conducted in 1954 on the hatching eggs of trout of different species at various temperatures. As indicated in Table 2, lake trout, Atlantic salmon and brook trout eggs were successfully incubated at a temperature below 37°F. but rainbow trout eggs did not hatch at this low temperature. At a temperature above 50°F. rainbow trout eggs were incubated successfully but eggs of lake trout and Atlantic salmon died and brook and brown trout eggs showed low survival.

Two factors which can change the spawning time of trout are water temperature and amount and duration of light. Lagueux (1954) observed that brook trout spawners kept, for one year, inside a dark hatchery instead of outside spawned two months later than usual. Seguin (1951) caused brook trout fingerlings, which had been reared in water of high temperature (50 to 61° F.) to spawn from 10 to 11 months sooner than those raised in water of 43 to 52 F. under the same lighting conditions. With the higher water temperature some 11-inch and three-quarter-pound fingerlings spawned for the first time at 13 to 14 months after the fertilization of the eggs instead of at an age of 24 to 25 months as is usual in the colder water.

During the period 1949 to 1955, a study made by the author on the artificial rearing of lake trout showed that incubation of eggs in very cold water, 33 to 37°F., gave very good results. It has also been observed that lake trout, as fry and fingerlings, can stand a temperature as high as 64°F. but they cannot live as yearlings, 4 to 6 inches long, in water exceeding 56°F. Current findings from another series of experiments made from 1953 to 1956, where the fish were kept in water temperature below 56°F., show that lake trout raised in the darkness of covered raceways have a much better rate of growth and better survival percentage than those

TABLE 2.—*Duration of incubation and mortality percentages of salmonid eggs at different temperatures*

Fish species	Water temperature, Degrees F.					
	33-37°		41-45°		50-55°	
	Duration (days)	Mortality percentage	Duration (days)	Mortality percentage	Duration (days)	Mortality percentage
Atlantic salmon	180	7	—	—	43	90[1]
Lake trout	170	4	89	10	—	100
Brook trout	165	10	84	5	44	50
Brown trout	138	14	89	5	36	38
Rainbow trout	109	95[2]	55	15[2]	30	12[3]

[1]40 percent mortality took place immediately after hatching.
[2]Fall-spawning trout.
[3]Spring-spawning trout.

raised without cover. Specifically, average weight was 140 grams and survival percentage 69.6 percent in 3-year-old lake trout reared in the light and the average weight was 202 grams and survival percentage 92.8 percent for those kept in darkness.

Transplantation of fish from one lake to another where the hydrographic conditions, such as temperature, light and altitude, differ may modify the spawning period of their progeny. In 1953, an experiment to determine the effect of such factors was undertaken. Brook trout from the Grand lac Jacques Cartier, Laurentide National Park, Que., where they normally spawn between August 20 and September 30, were transplanted to the Eastern Townships fish hatchery, where the same local species spawn between October 25 and December 1st. According to Vladykov (1942) and Legendre[4] the hydrographic conditions of the Grand lac Jacques Cartier are as follows: 47° 31' north latitude; 71° 14' west longitude; 2,600 feet altitude; ice leaves between May 15 and June 15; water is very cold; area is 2,800 acres and maximum depth is 195 feet. Growth of brook trout living in this lake is very slow. The Eastern Townships fish hatchery ponds are located at 45° 03' north latitude, 71° 55' west longitude, 1,400 feet altitude, and the summer season here is about two months longer and water is warmer than in the Park. The brook trout transplanted to the fish hatchery on August 25, 1952, spawned at the hatchery in the same year (1952) and the next year (1953) at the time on which they usually spawn in the Park. But their 1.5-year-old F^1 progeny, born at the hatchery, spawned for the first time (1954) two months later, and the second time (1955) a month later than the date at which their parents spawned in 1952 and 1953; but in both cases this was still a month ahead of the spawning date considered normal for fish of the same age in the Hatchery region.

[4]Legendre, V. Graphiques illustrant le volume du plancton et les conditions physico-chimiques du Grand lac Jacques Cartier, Parc des Laurentides (1938-1940). Typewritten Report, Quebec Biological Bureau, University of Montreal, P.Q. 1940.

Hybridization of Trout

A series of experiments on artificial hybridization of a number of salmonids was begun in 1948. Crosses have since been made using the following species: *Salvelinus fontinalis, Salvelinus namaycush, Salvelinus alpinus marstoni, Salmo gairdneri, Salmo trutta* and *Salmo salar.*

As shown in Table 3 the results obtained are as follows:

1. Growth and survival have been excellent for crosses between species of *Salvelinus:* the best growth was for the progeny of *S. fontinalis* ♀ and *S. alpinus marstoni* ♂.

2. *Salvelinus-Salmo* crosses gave poor results: the best was between *S. trutta* ♀ *and S. fontinalis* ♂.

3. *Salmo-Salmo* crossings did not give good results. However in these experiments no crossings were made between *S. trutta* and *S. salar* although Alm (1955) mentions that good results have been obtained from this cross.

4. Crosses between *S. namaycush* ♀ and *S. fontinalis* ♂ give better results than their reciprocal crosses.

5. Average number of eggs per 2.5-year-old *S. namaycush* x *S. fontinalis* hybrids, which are called splake trout, truite moulac or wendigo trout, is practically the same as for the reciprocal cross between these species. *S. namaycush* ♀ x *S. fontinals* ♂ hybrids gave an average of 909 eggs per female while the *S. fontinalis* ♀ x *S. namaycush* ♂ hybrids gave an average of 919 eggs per female.

6. Under our hatchery conditions, where water temperatures are between 33 and 68°F., the *S. namaycush* x *S. fontinalis* F^1 hybrids grew faster than *S. namaycush* but not faster than *S. fontinalis* for the first 3 years of their life. But growth has been more rapid on hybrids of this cross more than 3 years old than with *S. fontinalis* of the same age. For instance at an age of 1.5 years, under the same rearing conditions, 50 grams for the *S. namaycush:* 104 grams for *S. fontinalis* ♀ x *S. namaycush* ♂ hybrid; 154 grams for the *S. namaycush* ♀ x *S. fontinalis* ♂ hybrid, and 268 grams for *S. fontinalis.* At 2.5 years, 500 grams is the average weight of S. *fontinalis.* with 498 grams for the *S. namaycush* ♀ x *S. fontinalis* ♂ hybrid, and 392 grams for the *S. fontinalis* ♀ x *S. namaycush* ♂ hybrid. There are no data available for *S. namaycush.* since they could not stand the rearing conditions under which the other fish were kept. At 3.5 years, 850 grams is the average weight of *S. fontinalis.* with 1,134 grams for the *S. fontinalis* ♀ x *S. namaycush* ♂ hybrid, and 1,400 grams for the *S. namaycush* ♀ x *S. fontinalis* ♂ hybrid.

7. It was found that *S. fontinalis* x *S. namaycush* hybrids spawned at 2.5 years of age, whereas the *S. fontinalis* spawned at 1.5 years and the *S. namaycush* between 5 and 7 years. The eggs obtained from *S. fontinalis* ♀ x *S. namaycush* ♂ were better than those of the inverse crossing both as

TABLE 3.—*Results of trout hybridization experiments in Quebec*

Trout species[1]					Hybrids[2]			
Female	Male	Fall of year	Number of eggs incubated	Percent of eggs hatched	Age (year)	Weight (grams)	Percent survival and general condition	Size (inches)
Sf	Sn	1948	480	5.6	2.5	73	3	—
Sf	Sn	1949	—	—	0.2	0.15	57.3	—
					4.5	1386	—	—
Sn	Sf	1948	445	82	2.5	139	34.2	—
Sn	Sf	1949	—	—	0.2	0.20	94.5	—
					4.5	1400	—	—
Sn	Sam	1948	220	89.6	2.5	56	64.1	—
Sf	Sam	1948	650	87.9	2.5	168	68.4	—
Sg	Sf	1952	7,000	0	—	—	—	—
Sg	Sf	1953	5,000	5	0.2	0.36	G	1.0-1.5
					0.8	—	O	—
Sf	Sg	1952	10,000	1.7	—	—	G	—
Sf	Sg	1953	8,000	0	—	—	—	—
Sn	Sg	1952	5,600	0.1	—	—	G	—
Sn	Sg	1952	5,200	0.1	0.8	26.5	E	6
Sg	Sn	1952	8,000	0	—	—	—	—
Sg	Sn	1953	6,000	0.1	0.8	46.0	E	6
Sf	St	1953	3,800	0.1	0.8	7.6	E	2.7-4.0
St	Sf	1953	1,000	56	0.8	12	E	2.7-4.6
Sn	St	1953	900	0	—	—	—	—
St	Sn	1953	3,000	37.6	0.8	5	E	2.0-4.5
Sg	St	1952	8,000	12.5	—	—	F	—
Sg	St	1953	1,500	0	—	—	—	—
St	Sg	1952	3,200	0	—	—	—	—
St	Sg	1953	3,600	0	—	—	—	—
Ss	Sf	1954	1,800	0	—	—	—	—
Ss	Sg	1954	2,700	—	—	—	—	—
Sn x Sf	Sn x Sf	1952	10,000	70	0.3	—	27	—
Sn x Sf	Sn x Sf	1953	2,200	80	1	18.9	54	4.7-6.5
Sf x Sn	Sf x Sn	1952	19,300	75	0.3	—	49	—
Sf x Sn	Sf x Sn	1953	2,140	73	1	19.8	62	4.5-6.7

[1]SF — *Salvelinus fontinalis;* Sn — *Salvelinus namaycush;* Sam — *Salvelinus alpinus marstoni;* St — *Salmo trutta;* Sg — *Salmo gairdneri;* Ss — *Salmo salar.*

[2]Percentage survival and general condition is for weights, lengths and ages specified. General condition is noted as: F — fair; G — good; E — excellent.

regards survival and growth. One group of respectively 1.5-year-old *S. fontinalis* ♀ x *S. namaycush* ♂ and *S. namaycush* ♀ x *S. fontinalis* ♂ F^2 hybrids spawned for the first time in the fall of 1956 at the same age and time as the *S. fontinalis* spawners; another groups of 2.5-year-old *S. fontinalis* ♀ x *S. namaycush* ♂ and *S. namaycush* ♀ x *S. fontinalis* ♂ F^2 hybrids also spawned for the first time in the fall of 1956 at the same age and time as the F^1 hybrids. All the fish, parents, F^1 and F^2, were under the same rearing conditions.

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EFFECT OF STREAM IMPOUNDMENT IN TENNESSEE ON THE FISH POPULATIONS OF TRIBUTARY STREAMS

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Abstract

Data from a statewide survey of warm water streams in Tennessee were used to determine the extent to which gizzard shad *(Dorosoma cepedianum)*, carp *(Cyprinus carpio)*, smallmouth buffalo *(Ictiobus bubalus)*, and drum *(Aplodinotus grunniens)* inhabit smallmouth bass-rock bass streams. Reproduction of those species in tributary streams was minor or absent. By comparing samples from streams that were accessible from an impoundment and streams that were in an unimpounded watershed, it was shown that large populations of gizzard shad, carp, smallmouth buffalo, and drum in streams originate in impoundments. Mill dams on tributary streams were found to be effective barriers to the upstream movement of fish from the impoundment. Once reservoir fish populations were well established, there appeared to be no consistent variation in the populations of lake fish in tributary streams from one reservoir to another. In streams without migration barriers there was no decrease in the concentration of lake fish with an increase in the distance from an impoundment. Population pressure among fish of the various species in the impoundment is advanced as the reason for movement of gizzard shad, carp, smallmouth buffalo, and drum into streams. It is suggested that mill dams be preserved as barriers to movement of lake fish and that pre-impoundment surveys include consideration of the effect not only on the inundated stream but on the streams above the full-pool level of the proposed reservoir.

Introduction

Twenty years ago surface water in Tennessee was confined predominantly to flowing streams. The few power dams obstructing streams at that time backed up relatively small impoundments. In 1936, Norris Reservoir, the first of a long chain of lakes, was completed on Clinch River in East Tennessee by the Tennessee Valley Authority. Since that year, nearly 1,500 miles of warm water streams have been impounded by the Tennessee Valley Authority and the U. S. Army Corps of Engineers. Fifteen reservoirs were formed between 1936 and 1953. They range in area from 600 to 160,000 acres and total some 350,000 acres of impounded water in Tennessee.

The new "Age of Lakes" in Tennessee brought about broad changes in the dominant fish populations of the State. Although most species of fish now present were recorded for the State over 30 years ago, some of those fish now abundant in impoundments were comparatively rare in Tennessee streams before 1936. Populations of fishes favored by impoundment have expanded under these conditions to form the major part of the fish in Tennessee waters today.

FIGURE 1.—Tennessee, showing that portion lying east of Kentucky Reservoir with distribution of 119 stream sampling stations. The Cumberland drainage is represented as it was in 1953.

Reservoirs support about 75 percent of the fishing in Tennessee today while large and small streams account for most of the other 25 percent. Stream fishing is important because it satisfies both a multitude of cane-pole fishermen and a small, but avid, group of stream anglers. With the stream fishermen in mind, the Tennessee Game and Fish Commission conducted a warm water stream survey from June, 1952, to June, 1956. This survey was financed by funds from Federal Aid in Fish Restoration under Dingell-Johnson Project F-3-R.

Most factors influencing stream fish populations reflect conditions at the same or higher elevations in the watershed. Information collected in the course of the Tennessee stream survey suggested that conditions at lower elevations might also significantly influence stream fish populations because of upstream movement of fish species not native to the stream.

Preimpoundment surveys usually concern only the streams to be inundated. Little attention is given to those streams that are above the full-pool stage of the reservoir. The purpose of this paper is to present observations on relationships between impoundments and their tributary streams.

THE STREAM SURVEY

The stream survey was conducted during the months of June, July, August, and early September from 1952 to 1955, but data presented here are only for the years 1953 to 1955. The purposes of the survey were: (1) to determine the distributional patterns of stream fish species in the State, (2) to locate important fishable populations, and (3) to provide information for management of those streams which were worthy of special attention.

Although base maps showed all stream courses in the watersheds, they did not distinguish between seasonal streams or small rivulets and streams

with significant fish populations. This made it necessary for the survey party to select the sampling stations in the field. In West and East Tennessee, the number of sampling stations was predetermined for each major watershed. In middle Tennessee most emphasis was placed upon sampling the popular fishing streams. Primarily, warm water streams were sampled, but a few marginal trout streams were included incidentally. No large rivers with flows over 1,000 c.f.s. were included in this survey.

The fish were collected by use of an electrical shocker, powered by a 230-volt A.C., 115-volt D.C. portable Homelite generator. Paddle-type electrodes were used that were connected directly to the A.C. outlet of the generator. In most cases, the shocker was operated by two crewmen wading against the stream current and two men following with dip nets. The two electrodes were carried 3 to 20 feet apart, that distance varying with the conductivity of the water. Weight of all fish taken in the survey was recorded as pounds and ounces or grams, and total length was recorded as millimeters.

Approximately one-fourth mile of stream was sampled at each stream station. Estimation of the collecting efficiency of the shocker showed that 20 to 40 percent of the weight of all fish present was taken at each station. An attempt was made to sample each cover type in the same ratio that it existed at the sampling station. An average of 41 pounds of fish was taken for the sampling stations considered in this report.

Species composition of fish samples taken is reported as percentage of total weight. The large number of streams to be sampled in a limited time made it impossible to obtain a reasonable estimate of the total population at each station.

Description of Streams

Small streams in Tennessee consist of three general types: (1) the smallmouth bass-rock bass streams found in Middle and East Tennessee, (2) the spotted bass-catfish streams of West Tennessee, and (3) the mountain trout streams in the Appalachians of East Tennessee. The stream type considered in this paper is the first type, the smallmouth bass-rock bass stream. This stream type is found only east of Kentucky Lake (Figure 1).

Smallmouth bass-rock bass streams in Tennessee are generally 20 to 150 feet wide and have an average stream flow of less than 1,000 c.f.s. There are frequent riffles of gravel and rubble, and limestone or sandstone bedrock may be exposed. The pools are from 2 to 20 feet deep. In the lower portions of some streams, pools may be 600 to 800 yards long, but in most streams, pools are 50 to 300 yards long. Water temperatures seldom rise above 80°F. In the more stable streams, bars of gravel and small rubble are restrained by rich growths of water willow *(Justicia americana)*.

Chemical conditions in the smallmouth bass-rock bass streams vary widely in Tennessee. In Middle Tennessee, where the principal rock strata

are limestone, the water has a hardness as great as 200 p.p.m., expressed as total alkalinity, and is seldom less than 100 p.p.m. In the Appalachian Range of East Tennessee and on the Cumberland Plateau, rock formations are respectively mainly of igneous origin and sandstone. Streams in these formations have soft water. The total alkalinity of water in these areas is generally below 70 p.p.m. and is often less than 10 p.p.m. Shoup (1950) examined waters from the East Tennessee mountains and found total alkalinities usually below 50 p.p.m. He found that waters of the Cumberland Plateau were mostly below 25 p.p.m. in total alkalinity. Between the Cumberland Range and the Appalachian Range is an area underlain by limestone where the chemical characteristics of the streams are similar to those of Middle Tennessee.

In 1953 and 1955, 119 separate fish samples were taken from the smallmouth bass-rock bass type of stream. The most abundant, in terms of total weight, of the species assumed to be indigenous to this type of stream, were the golden redhorse *(Moxostoma erythrurum)*, hogsucker *(Hypentelium nigricans)*, longear sunfish *(Lepomis megalotis)*, rock bass *(Ambloplites rupetris)*, smallmouth bass *(Micropterus dolomieu)*, and stoneroller *(Campostoma anomalum)*. Fifteen other species of native stream fish occurred widely but in small numbers. They are, however, considered to be normal components of this fish association. Other species which were found to be present but not believed to be native to this type of stream were the largemouth bass *(Micropterus salmoides)*, bluegill *(Lepomis macrochirus)*, carp *(Cyprinus carpio)*, drum *(Aplodinotus grunniens)*, smallmouth buffalo *(Ictiobus bubalus)*, gizzard shad *(Dorosoma cepedianum)*, white crappie *(Pomoxis annularis)*, and black crappie *(Pomoxis nigro-maculatus)*. The presence of these non-stream fish in smallmouth bass-rock bass streams is the basis for the present discussion. As a matter of convenience, largemouth bass and bluegills will be designated "pond fish," and carp, drum, smallmouth buffalo, gizzard shad, and the crappies collectively will be designated "lake fish" in the following discussion.

Lake Fish in Streams

Since the material for this discussion is from a general statewide stream survey, information on all factors relative to the presence of lake fish in tributary streams is not available. There is, however, a basis for comparison of stream populations. Among the problems to be considered as to origin and presence of lake fish in streams are: (1) the extent of lake fish reproduction in streams, (2) the effect of mill dams and waterfalls on the movement of lake fish in streams, (3) extent of movement of lake fish in streams, (4) variation in concentration of lake fish in tributary streams from reservoir to reservoir and (5) comparison of the fish populations of the tributary streams of an impounded river with those of an unimpounded river.

Lake Fish Reproduction in Streams

Those species referred to above as lake fish occur more commonly in lakes, large rivers, and large impoundments than in tributary streams and small rivers in Tennessee. It is assumed that such small streams do not offer suitable spawning conditions for those species. From observations on the Obed River, Cumberland County, Tennessee, in 1952 and 1953, Parsons[1] states that 75 percent of the weight of all fish taken with hoop nets was of migrants from Watts Bar Reservoir. These fish included gizzard shad, carp, smallmouth buffalo, and drum. He further states that none of these lake fish showed evidence of successful reproduction in Obed River. All carp and smallmouth buffalo were longer than 13 inches, and most were sexually immature.

In the Tennessee survey, drum were found in equal percentages in streams associated with large rivers and streams associated with impoundments. Forbes and Richardson (1920) indicated that the drum was found with equal frequency in large rivers and lakes in Illinois. No reproduction of drum was found in any of the Tennessee tributary streams. Eschmeyer, Stroud, and Jones (1944) found that young-of-the-year drum taken from Chickamauga Reservoir in Tennessee were of an average total length of 3.5 inches in September. In Kentucky, Tompkins and Carter (1951) determined that drum taken from lakes averaged 4.3 inches in total length at the first annulus, while those from streams had an average length of 4.9 inches at the first annulus. The smallest drum taken in the Tennessee survey of tributary streams was 6 inches in total length, and 11 fish were less than 8 inches. Although advanced young-of-the-year may be among the smaller drum taken, it is concluded that few young drum were raised in tributary streams.

Smallmouth buffalo were abundant in some streams but were not widespread in distribution. They were present at 4 of 119 sampling stations. They made up 15 to 25 percent of the total weight in three of those samples and one fish was collected in the fourth sample. The smallest buffalo taken in collections was 13.6 inches long suggesting that no reproduction occurred in those streams. Eschmeyer, Stroud, and Jones (1944) found that smallmouth buffalo averaged 3.8 inches at the first annulus. Candy Creek and North Mouse Creek, on which were two of the sampling stations at which buffalo were collected, are tributaries of the Hiwassee arm of Chickamauga Reservoir.

Gizzard shad occurred at 34 sampling stations. Data are lacking on the ages of the shad taken, but field observations indicated that young-of-the-year fish were uncommon in the samples. Too few crappie, both white and black, were taken to justify their consideration here. Five crappie were taken at three sampling stations.

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[1]Parsons, John W., A preliminary report of the fish population studies on Obed and Emory Rivers, Tennessee. Mimeographed report presented before The Southeastern Association of Game and Fish Commissioners in Chattanooga, Tennessee, 1954.

Carp occurred at 42 of the sampling stations. They were the most abundant lake fish in terms of total weight. It is possible that no carp reproduction occurred in tributary streams. Small carp taken were of a size that could be either advanced young-of-the-year or retarded yearlings. Eschmeyer, Stroud, and Jones (1944) state that young-of-the-year carp taken from Chickamauga Reservoir in September had a maximum total length of 5.9 inches and that yearlings from the same water averaged 10.1 inches at the first annulus. A total of 205 carp was taken from 119 sampling stations on smallmouth bass-rock bass streams. Twenty-three of those fish were less than 10 inches in length and only three were less than 7 inches long. Three carp taken from Big Sewee Creek in Meigs County in early September were 5.0 to 6.5 inches long. Although it was possible that carp reproduced successfully in some tributary streams, it is not likely that native stream reproduction was responsible for the large carp populations found.

Largemouth bass or bluegills or both were found to occur at 61, or about half the sampling stations. Numbers at any station were small, seldom exceeding 10. The total weight of the pond fish exceeded 5 percent of the total weight of the sample only at four stations. Largemouth bass reproduction appeared at two stations, and young-of-the-year bluegills were found at seven stations. Evidence collected suggested that most pond fish found in smallmouth bass-rock bass streams originated in ponds and lakes upstream rather than in large impoundments downstream from the point of collection.

Effect of Mill Dams

Study of the fish distribution data indicated that stream sampling stations which were accessible from large impoundments below, contained lake fish more frequently than did stations which were above mill dams and inaccessible from impoundments. There were 44 stations located on streams which were obstructed by mill dams at some point. Thirty of those stations were located so that a dam separated them from any large

Table 1.—*Composition of fish samples from stream stations above and below mill dams*

Location of stations	Number of stream stations sampled	Number of stations with no lake fish	Composition of fish samples by percentage of total weight[1]					
			Gizzard shad	Carp	Small-mouth buffalo	Drum	Crappie	All lake fish
Above dams	30	23		2			—	2
Below dams	89	35	6	17	1	1	—	25

[1]Percentages obtained by first combining the weights of all samples including those with no lake fish. Dash (—) indicates occurrence of less than 1 percent.

FIGURE 2.—Concrete mill dam on Hurricane Creek that acts as an effective barrier to movement of lake fish from Kentucky Reservoir.

impoundment or river below (Table 1). The dams (mostly associated with grist mills) were 4 to 30 feet high and constructed of timbers or concrete and rock (Figure 2).

Seven of the 30 stations above dams contained lake fish which included only carp and crappie. At two of these stations four black crappie were taken, and at four stations 10 carp were taken. The greatest number of carp from one station above a dam was five. Lake fish made up 2 percent of the weight of all fish taken from the 30 sampling stations upstream from mill dams. At stations where lake fish were collected, lake fish made up 9 percent of the weight of all fish. Eighty-nine sampling stations were located below mill dams which impeded upstream movement of fish. One lake fish or more was found at 54 of these stations. Lake fish comprised 25 percent of the total weight of all fish collected at the 89 stations below dams. At those stations where lake fish were taken, they made up 36 percent of the weight.

It is assumed, on the basis of fish taken above and below stream obstructions, that most mill dams and waterfalls are effective barriers to

the upstream movement of lake fish. Though some dams may be passable, particularly during periods of flood, they prevent carp from infesting the upper reaches of streams in large numbers. Distribution of lake fish above dams may indicate that some of these obstructions are more or less negotiable. Although Parsons[1] found that Hester Falls, a series of rapids and falls on Obed River, was a barrier to the movement of non-game fish from Watts Bar Reservoir, apparently a few carp, smallmouth buffalo, and drum negotiated the obstruction.

As was pointed out, lake fish, particularly carp, apparently do not reproduce successfully in tributary streams, so those fish which manage to negotiate an obstruction will not establish a permanent population above. Most dams which apparently prevented the passage of fish were more than 8 feet in height. Some 6-foot dams seemed effective, but carp were found above much higher dams. It is obvious that the site of the dam and the height of the flood are also important. Although carp may have gained access to waters above dams by other means, it is assumed in the present discussion that the carp taken negotiated obstructions during flood periods.

Extent of Movement in Streams

All points on streams in the Tennessee River drainage are probably accessible to fish from impounded waters at some time during the year, unless they are above an impassable dam or waterfall. At stream stations located on streams without barriers and from one to 110 miles from the

Table 2.—*Abundance of lake fish and distance of sampling stations from nearest impoundment downstream*[1]

Distance of sampling station in miles from impoundment	Number of stream stations sampled	Number of stations with no lake fish	Composition of fish samples by percentage of total weight[2]					
			Gizzard shad	Carp	Small-mouth buffalo	Drum	Crappie	All lake fish
0-9	12	2	5	31	2	3		41
10-19	16	1	11	18	5	3		37
20-29	5	1	6	15		1		22
30-39	4	3		3				3
40-49	4	1	2	33		—		35
50-59	4	3	4	6				10
60-69	3		13	17		1		31
70-79	4	2	4	13		1		18
80-89	3	1	4	12			1	17
90-99								
100-109	2		4	47		2		53
110-119	1	1						

[1]Only stations with no obstructions to fish below them included.
[2]Percentages obtained by first combining the weights of all samples including those with no lake fish. Dash (—) indicates occurrence of less than 1 percent.

[1]Parsons, John W., A preliminary report of the fish population studies on Obed and Eory Rivers, Tennessee. Mimeographed report presented before The Southeastern Association of Game and Fish Commissioners in Chattanooga, Tennessee, 1954.

nearest impoundment, no marked relationship could be detected between the abundance of lake fish and the distance from the reservoir (Table 2). Stations more than 100 miles from an impoundment contained a higher proportion of lake fish than did those samples taken less than 10 miles from an impoundment. Also, the number of sampling stations that contained lake fish did not show any relation to the distance from the impoundment.

Lake Fish in Streams in Relation To the Receiving Reservoir

In general, reservoirs in the Tennessee River system are similar in their suitability for gizzard shad, carp, drum, and smallmouth buffalo. Impoundments within the watershed are, however, of two major types: (1) mainstream reservoirs, and (2) storage reservoirs. Mainstream reservoirs are located on the Tennessee River and are characterized by relatively minor fluctuations in water levels throughout the year. Storage reservoirs, intended primarily for flood control and power, are located on the larger tributaries, and the water levels may fluctuate as much as 100 feet annually. No studies have been conducted to determine the effect of fluctuation on abundance of the above species. Any consistent effect of water level fluctuation is not apparent in population samples collected by biologists of the Tennessee Valley Authority in recent years. Watauga and Boone Rerservoirs, both storage reservoirs, are two of the newest impoundments. Carp have not appeared in the samples from Watauga Reservoir but are abundant in the Boone samples.

Table 3.—*Percentage of lake fish by weight in samples taken from streams tributary to Tennessee impoundments*[1]

Receiving impoundment[2]	Number of stream stations sampled	Number of stations with no lake fish	Composition of fish samples by percentage of total weight[3]					
			Gizzard shad	Carp	Small-mouth buffalo	Drum	Crappie	All lake fish
Watauga	2	2						
Boone	5			26				26
Cherokee	4		4	50				54
Douglas	9	3	8	3				11
Fort Loudoun	2			50		3		53
Norris	2	2	30	3		1		34
Watts Bar	3	1	1	36	2	3		42
Chickamauga	7	2	8	29	18	7		62
Wilson	3		6	15		1		22
Kentucky	22	7	9	20		1	—	30

[1]Only stations with no obstructions to fish below them included.
[2]Fort Loudoun, Watts Bar, Chickamauga, Wilson, and Kentucky reservoirs are mainstream reservoirs. All others are storage reservoirs.
[3]Percentages obtained by first combining the weights of all samples including those with no lake fish. Dash (—) indicates occurrence of less than 1 percent.

There is no consistent pattern apparent in the lake fish populations of tributary streams of different reservoirs (Table 3). Nor is the composition of samples of fish populations from reservoirs necessarily reflected in the composition of fish samples from tributary streams. It is of interest to note that the absence of carp in the Watauga stream samples is supported by a corresponding absence of carp in the reservoir sample. Carp appeared in samples from all other reservoirs and in at least some of their tributary streams. Smallmouth buffalo appeared in the tributary streams of only two reservoirs. According to the reservoir population samples, buffalo were more abundant in those two reservoirs than in others. It is also of interest to note that pond fish, almost entirely largemouth bass and bluegills, were present in the streams of all reservoirs except Boone and were consistently less than 2 percent of the total sample.

Distribution and Abundance of Fish in an Unimpounded Drainage

The Tennessee River and its major tributaries are almost completely impounded from Paducah, Kentucky, to Bristol, Tennessee. The Cumberland River enters the Ohio River 13 miles above the mouth of the Tennessee River. The headwaters of both rivers are located near the Kentucky-Virginia border. The Cumberland forms the inside curve and the Tennessee the outside curve of a great crescent in which lies the middle part of Tennessee (Figure 1).

There are no unobstructed streams in the Tennessee River drainage basin that are not accessible from a large impoundment. East Tennessee particularly has many impoundments. The Cumberland River drainage was not impounded until 1943 when the Dale Hollow dam was completed on the Obey River. Center Hill dam impounded the Caney Fork in 1949. There were no impoundments on the Cumberland itself until Wolf Creek dam was completed in Kentucky in August, 1950. Old Hickory and Cheatham reservoirs near Nashville were partially impounded in 1954. Before 1954 there had been 461 miles of the Cumberland River and many more miles of tributaries free from the influence of large impoundments. The survey of the Cumberland River took place in 1953.

Duck River is one of the largest of the tributaries of the lower Tennessee River. It flows roughly parallel to the Cumberland River and enters Kentucky Lake near its mid-point from the east. Although Duck River carries only one-fifth as much water as the Cumberland River in the areas under consideration, both streams have big-river characteristics.

Many of the typical smallmouth bass-rock bass streams in Tennessee are tributaries to the Cumberland and Duck Rivers. Tributaries of Duck River are accessible from Kentucky Reservoir while the Cumberland River tributaries were not subject to the influence of a downstream impoundment at the time of the survey.

A comparison of the fish samples from the tributaries of the two drainages revealed quite different populations (Table 4). Sixteen of the stations in the Duck River watershed were readily accessible to fish from Duck River and Kentucky Reservoir. On the Cumberland River watershed, 24 sampling stations were readily accessible to fish from the unimpounded river. There were no obstructions to interfere with fish movements from the Cumberland River to any of these sampling stations in the watershed. Typical stream fish species made up 73 percent of the total weight of all fish taken from sampling stations in the Duck River watershed. Stream species made up 97 percent of the fish in samples from Cumberland tributaries. The concentration of pond species was essentially the same in the two watersheds. Drum, apparently a large-river fish as much as a lake fish, was equally abundant in the tributary streams of each watershed. Gizzard shad were less than one-third as abundant in the Cumberland samples as in the samples from the Duck tributaries.

TABLE 4.—*Occurrence of lake fish in samples from stream stations accessible from an impoundment and from an unimpounded river, 1953*[1]

Receiving river	Number of stream stations sampled	Number of stations with no lake fish	Composition of fish samples by percentage of total weight[2]				
			Gizzard shad	Carp	Drum	Crappie	All lake fish
Duck River tributary to Kentucky Lake[3]	16	7	7	19	1	—	27
Cumberland River, not impounded	24	8	2	—	1	—	3

[1]Only stations with no obstructions to fish below them included.
[2]Percentages obtained by first combining the weight of all samples including those with no lake fish. Dash (—) indicates occurrence of less than 1 percent.
[3]Tennessee River impounded to form Kentucky Lake.

The greatest difference in the two populations was in the number of carp. Carp comprised 19 percent of the total weight of all fish taken in the Duck River tributaries. Two carp, making up less than 0.5 percent, were found in the Cumberland tributaries.

Lake fish in tributaries of the Duck River were not distributed among all sampling stations. Carp were found at seven sampling stations and gizzard shad were taken at eight of the 16 stations. Drum were taken at three sampling stations, and were always found with carp or shad. Less than half of the stations in the Duck River watershed had no lake fish. In the Cumberland watershed, 16 stations, or 66 percent, had no lake fish. None of the Cumberland stations had shad, carp, or drum in abun-

dance. None of the carp taken in either watershed was less than one year old. The smallest specimen was taken from Buffalo River and was 13 inches long.

Carp, gizzard shad, smallmouth buffalo, and drum were taken in all population samples from Kentucky Reservoir in 1953. This reservoir receives Duck River. A limited amount of information is available on fish populations of the Cumberland River. There is no information before Cheatham and Old Hickory dams were constructed. Biologists of the Tennessee Game and Fish Commission collected fish samples on partially-impounded Cheatham and Old Hickory reservoirs in Davidson and Wilson counties in August, 1955. Samples were taken in Cumberland River 130 to 170 miles above Old Hickory Dam in July, 1956. Carp were present in two Old Hickory samples and one sample from the upper Cumberland River and made up 3 to 13 percent of the weight of each of those samples. Gizzard shad and drum were present in all seven samples. The shad ranged from 3 percent in one of the channel samples to 87 percent in a Cheatham cove. Drum were rare in cove samples but ranged from 27 to 57 percent of the weight of each sample from the channel. While these samples may not represent the true population in the Cumberland at the time the tributaries were surveyed, it suggests that fish of these species were present in the river before it was impounded.

During the months of December, 1955, and January, 1956, a controlled gigging (spearing) season was opened on Buffalo River, a tributary of Duck River and Kentucky Lake. During five weeks on 100 miles of the stream, it was estimated that not less than 25,000 pounds of rough fish were taken from the stream by gigging. The take consisted of approximately 42 percent carp, 12 percent smallmouth buffalo, 16 percent drum, two percent hogsuckers, 19 percent redhorse *(Moxostoma* spp.), six percent longnose gar *(Lepistosteus osseus)*, and three percent gizzard shad, paddle fish *(Polyodon spathula)*, and bowfin *(Amia calva)*.

Management of Tributary Streams

It is postulated from the foregoing data that the favorable conditions for spawning of gizzard shad and carp in Kentucky Reservoir allowed a large population to develop. Individuals seeking to escape the consequent population pressure, found that tributary streams offered an avenue of escape from the reservoir. On the unimpounded Cumberland River, the opposite appears true. There, spawning areas for shad, buffalo, and particularly carp seemed to be few in number, and populations before impoundment were not great. Relatively few individuals of typical lake species were produced, population pressure was low, and those species seldom appeared in tributaries of the Cumberland River.

A number of streams now under observation in Tennessee are known to have declined in quality and quantity of smallmouth bass and rock bass angling within the period that infiltration by carp is judged to have taken place. Collections of native stream species in the Tennessee stream survey were larger in streams in which lake fish were rare or absent. Further investigation remains to be carried out to learn the exact relationship between lake species, particularly carp, and smallmouth bass and rock bass in streams. Should the relationship be detrimental to the native species, a satisfactory type of barrier to lake fish has been demonstrated in mill dams already in place on some Tennessee streams.

Until the relationship between stream-inhabiting lake species and native smallmouth bass and rock bass is more clearly understood, it is important that smallmouth bass-rock bass streams be protected as much as possible from influx of lake species from downstream impoundments. Although many such streams are now protected by waterfalls or mill dams, there are requests for removal of small dams "so bass can get up stream." In light of the data presented, careful consideration should be given to the value of the stream or its tributaries for smallmouth bass or rock bass before any mill dams are removed.

Quantitatively the sport fishing potential of an impoundment is usually greater than that of an unimpounded stream. However, quality of fishing must be considered. Many smallmouth bass-rock streams in Tennessee offer a type of angling that cannot be found in impoundments, and the sport of anglers who enjoy stream fishing should not be allowed to disappear. High-quality smallmouth bass-rock bass habitat among the tributaries of a proposed impoundment should be fully evaluated in any pre-impoundment survey and steps should be taken to preserve those streams in their original state.

Acknowledgments

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APPLICATION OF UNDERWATER TELEVISION TO FISHING GEAR RESEARCH

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Abstract

Development and application of closed circuit underwater television for use in fisheries investigations is described. It has been used successfully in Florida coastal waters as a tool in studies of marine fishery methods and equipment.

In marine fisheries investigations, and particularly in research into fishery methods and equipment the object of research is largely hidden from view beneath the sea. Here techniques of sampling or the traditional trial and error methods based upon analysis of fish catches of the gear, have not allowed adequate definition of the problems involved in the design, construction and use of such gear. Some valuable contributions have been made by divers with cameras, but gathering information in this way is usually difficult and may be extremely hazardous. With the appearance of a new research tool, the underwater television camera, there is now promise of easier systematic observation and investigation of fishing gear in operation.

Since July 1954, the Gear Research and Development Program of the United States Fish and Wildlife Service at Coral Gables, Florida, has been engaged in the underwater application of closed circuit television, to observe and test the performance of existing and experimental types of fishing gear under field conditions. A standard vidicon closed circuit television system was modified for use at lower light levels encountered undersea and enclosed in a water-tight steel cylinder. During early experimental evaluation, the television camera was affixed to simple water sleds which were towed and controlled by vanes or rudders. It was used to obtain views of trolled lures, model trawls, and trawl doors. By suspending the camera over the side of the vessel or placing it near the bottom excellent observations were obtained of lobster traps, coral formations, bottom topography, water conditions and marine life.

It was found that under favorable conditions with only natural sunlight for illumination, in the clear waters adjacent to the Florida east coast, good views might be obtained of fishing gear from close-up range to dis-

stances of 60 to 70 feet at depths in excess of 60 feet. With the addition of a remote iris control to the television camera, and artificial lighting, the depth range was extended, although it was still dependent upon weather and water conditions. Images seemed somewhat flat because of the diffused light underwater but the addition of motion or of artificial light to the scene tended to produce some shadow effect and afford more natural views to the operator at the monitor.

In November of 1954, an underwater television project was conducted jointly by the U. S. Fish and Wildlife Service and the Bureau of Ships in the Gulf Stream waters off the Florida coast to observe full-sized experimental midwater trawling gear. Aboard the Service research vessel *Oregon* an image orthicon television camera was positioned astern between the vessel towing warps. Excellent views were obtained of the towing warps, trawl doors, and the trawl mouth revealing floats, leads and meshes in detail. At the same time the Service research vessel *Pompano* positioned a vidicon camera alongside the trawl for lateral views of the trawl in operation. The entire operation was recorded on motion picture film. By means of these observations and evaluations of the experimental trawl, it was possible for Service engineers to modify satisfactorily net design and construction by application of physical and engineering principals. The new net designs were successful in midwater-trawling operations off the Washington and British Columbia coasts in May and June of 1956. These were carried out jointly by the U. S. Fish and Wildlife Service and the Canadian Pacific Biological Station.

From these successful early experiments stemmed a prototype undersea television vehicle designed and constructed by U. S. Fish and Wildlife Service engineers at Coral Gables, Florida. In this device the television camera, housed within the water-tight cylinder, is mounted in a submersible, free-flooded ball-type remotely controlled diving bell. The camera is connected by a gear train to a water-tight power driven control unit which affords the operator remote control of the television camera's scan of 360° in azimuth, 90° in elevation. The image seen at the television camera is propagated over a multiconductor cable to the monitor screen aboard the research vessel. This unit may descend to depths of 50 fathoms, may be towed at speeds to four knots with excellent picture stability, may hover above the objective as desired, or be placed on the bottom and remain submerged for extended periods of time for around-the-clock observation when desired.

From January through March of 1955, the underwater television vehicle was used in observations of commercial shrimp trawls under actual fishing conditions in the Key West-Tortugas area. While these trawls were ascertained to be fishing as designed, it was possible for fishery scientists to adjust floats, leads and trawl doors and so to improve the fishing ability of the gear. During this same period the underwater television vehicle

was used with underwater sound gear, shrimp traps, and other gear in connection with studies of shrimp in their natural habitat in the Key West area. The sounds produced by pink shrimp *(Penaeus duorarum)* were identified by underwater sound researchers. Characteristic sounds resembling those produced by pink shrimp were more properly attributed to the Florida lobster, *(Panulirus argus),* with the aid of the television camera. In a controlled experimental observation specimens of pink shrimp were seen by the television camera to bury themselves in the sand during daylight hours with only their eyes exposed to view.

To a certain extent it has been possible to observe the behavior of fishes with respect to the gear. During midwater trawl experiments in November 1954, small schools of sardines *(Sardinella aurita)* and cigarfish *(Decapterus punctatus)* were observed swimming easily in front of the trawl by the television camera, as if aware of the net but merely avoiding it. On another occasion in the Gulf Stream in midwater trawl tests, the same species were observed to be darting about in all directions as if alarmed by the trawl. With the television camera it should be possible to observe trawl mesh configuration, stresses, strains, knot slippage, water flow and other factors affecting rational design and construction of fishing gear and the efficiency of specific mesh sizes or fibres of certain species of fishes.

With the underwater television vehicle many square miles of bottom area have been examined in a day. Existing fishing grounds, shellfish beds, bottom topography and water conditions have been examined in closer detail than heretofore possible. With this form of instrumentation direct observations may be obtained of temperature, turbidity, light intensity and other factors affecting the commercial fisheries and related marine investigations.

It has been said that the sensitivity of the television camera exceeds that of the human eye by many times because of its ability to admit and accommodate light. This has not been found to be true by U. S. Fish and Wildlife Service research technicians to date and a much closer estimation of this ability might be said to be two to three times this sensitivity. What is more important is that while the image quality of the human eye may not be surpassed by the television camera, with new and rapidly appearing electronic developments, the television camera, with appropriate lenses for camera and photographic recording gear, may with a greater ability to integrate light, equal the scope of human vision in terms of definition and tonal quality.

In terms of flexibility, mobility, time of immersion, freedom from risk or hazard of depth and pressure, the underwater television camera offers a promising tool to the fishery scientist. He may now, with the combination of television camera and photographic recording camera, be able to see more clearly some of his problems, record them and take them back to the laboratory for detailed analysis and solution.

COMPARISON OF DRIED YEASTS, *CANDIDA UTILIS* AND *SACCHAROMYCES CEREVISIAE,* AS SUPPLEMENTS IN A DIET FOR RAINBOW TROUT

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ABSTACT

A single grade of the yeast *Saccharomyces cerevisiae* and three grades of the yeast *Candida utilis* were tested as growth stimulants and as vitamin sources when fed in a dry pelleted diet to rainbow trout. At levels of 4 percent, 8 percent and 15 percent of dry yeast in the diet, growth was stimulated and conversion ratios improved. Maximum growth occurred on 8-percent yeast diets. With the exception of one grade of *C. utilis,* all yeasts at the same levels in the diet gave similar results.

Vitamin analyses indicated that diets enriched with 4-percent of yeast were deficient in meeting the daily requirement levels of B-vitamins. Because no appreciable mortality occurred after feeding these diets for 18 weeks, it is suggested that reported daily requirements are high. Storage of diets at room temperature for 180 days had little destructive effect on B-vitamin content, except some loss in niacin occurred. A commercial pelleting process effected no loss in B-vitamin content.

The mortalities of trout on yeast-fortified diets and the yeast-free diet were similar. Liver necrosis in trout on the diets for 33 weeks appeared to a like degree for all diets tested. At similar levels in the diet, *C. utilis* yeasts promoted higher storage levels of biotin. Trout on 8-percent yeast diets had less liver biotin than those on 4-percent yeast, 15-percent yeast and yeast-free diets.

When trout are fed a pelleted diet at 60 percent of that recommended in Cortland Feeding Chart, they attained a coefficient of condition, empirically expressed as "R", of 1.80 to 1.86 on the yeast supplemented diets and of 1.73 on the yeast-free diet.

INTRODUCTION

Studies reported here compare the nutritional value of torula yeast, *Candida utilis,* and brewers' yeast, *Saccharomyces cerevisiae,* in a pelleted diet for rainbow trout. To find their comparative values as growth stimulants and as vitamin sources, chemical and biological assays of the experimental diets containing different amounts of yeast were conducted.

Dried yeast, especially brewers' yeast, has long been included in diets for trout to stimulate growth and to supply added nutrients, particularly vitamins of the B-complex. Torula, or wood yeast, *C. utilis,* was used as a supplement to stimulate growth by Churchill (1952) in a fresh meat diet fed to brook trout. He compared the growth rates of brook trout

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on meat diets containing brewers' yeast and torula yeast and found that both yeasts gave better growth than a yeast-free control diet. In this experiment, trout fed torula yeast grew better than those fed brewers' yeast. A comparison of feeding value of dried yeast from various sources by Phillips, *et al.,* (1950) demonstrated that 8-percent dried brewers' yeast in a diet containing a mixture of fresh meat and dry meal, produced superior growth and lower mortality than a similar yeast-free diet. Addition of 5-percent brewers' yeast resulted in a marked reduction in mortality and lowered the amount of "blue-slime" *(biotin avitaminosis)* present in brown trout.

Diets and Experimental Feeding

Lots of 300 fingerling rainbow trout (10.7 fish per pound) were placed in standard hatchery troughs supplied by water from a spring. The water

Table 1. *Composition of control diet (No. 11) fed as 3/32-inch pellets to rainbow trout.*

Ingredient	Percentage of diet by weight	Percentage composition of diet ingredient[1]			
		Protein	Fat	Fiber	Ash
Wheat red dog flour	28	16.0	3.5	3.0	3.0
Cotton seed meal solvent extracted	21	41.0	0.5	13.0	6.0
Fish meal (white fish)	15	63.0	6.0	0.5	20.0
Corn distillers' dried solubles	12	26.0	3.0	3.5	8.0
Animal liver meal	10	62.0	10.0	2.0	3.0
Skim milk, dry	10	34.0	1.0	0.1	8.0
Vitamin A and D feeding oil	2	2250 U.S.P. units A per gram 300 I.C. units D per gram			
Iodized salt	2				

[1]Minimum values for protein and fat; maximum value for fiber.

had a temperature of 50°F. (10°C.) with a deviation of no greater than one degree. These fish were fed pellets of 3/32-inch diameter that contained different kinds and amounts of dried yeast. A control diet (Table 1) and 10 modifications of it were used. The control with 8 percent dried yeast was the standard diet in Wisconsin's trout hatcheries. Replacement of part of the wheat red dog flour in the control diet was made to include 4-percent, 8-percent and 15-percent dried yeast in the several experimental diets. Diet Nos. 1 through 4 had four percent yeast, 5 through 8 had eight percent yeast and diet Nos. 9 and 10 had fifteen percent yeast (Table 2). Diet No. 11 without yeast, was the control.

Rainbow trout in duplicate lots were fed either one of the experimental

diets or the control diet for 18 weeks, November 4, 1955 to March 11, 1956. Food was weighed on a dietetic gram scale to the nearest gram. The daily amount fed was 60 percent of the amount recommended in the Cortland Feeding Chart (Tunison, 1945) for rainbow trout in water at 50°F. Fish in each trough were weighed at the beginning of the experiment and at two- to three-week intervals during the experiment. After each weighing, the daily portion of food was increased because of the gains in weight made by the lots of fish. Each lot was fed at the same percentage of body weight per day.

After 18 weeks, the duplicated feeding trials were terminated because some of the troughs were needed for production, and the experiment was continued with a single trough of fish for each diet. Data on growth and conversion in this paper were for the 18-week period when duplicate

TABLE 2. *Kinds and amounts of dried yeast used in experimental diets fed to rainbow trout.*

Kind of yeast	Diet numbers with 4 percent yeast	Diet numbers with 8 percent yeast	Diet numbers with 15 percent yeast
Saccharomyces cerevisiae			
food grade	1	5	10
Candida utilis			
food grade	2	6	—
feed grade	3	7	9
feed grade high thiamin	4	8	—

troughs were used. Single lots of trout were fed on the diets described for a total of 33 weeks, until June 21, 1956. At that time, trout were selected at random from each trough to determine concentrations of fat and biotin in the livers. Gross pathological examination of livers was made from other trout of these lots.

Chemical determinations were made under a contract with the Wisconsin Alumni Research Foundation, Madison, Wisconsin.

The dried yeast *S. cerevisiae* was purchased from Standard Brands, Inc., New York, New York. The dried torula yeast, *C. utilis*, was obtained in three grades from the Lake States Yeast Corporation, Rhinelander, Wisconsin.

EFFECTS OF DRIED YEASTS, STORAGE AND PELLETIZATION ON VITAMIN CONTENT OF DIETS

As shown in Table 3, the addition of 4 percent yeast to the control diet provided an increase in the seven B-complex vitamins. The experimental diets had similar concentrations of B-vitamins with the exception of folic acid, niacin and thiamin. Supplementation with *C. utilis*, food grade, in diet No. 2, yielded greater concentrations of niacin and thiamin. All diets fortified with *C. utilis* (Nos. 2, 3 and 4) were higher in folic

TABLE 3. *Effects of supplementing with 4 percent yeast, of storing at room temperature for 30, 90 and 180 days and of pelleting on the vitamin content of pelleted trout diets.*

Diet number	Days stored	Vitamin content as milligrams per 100 pounds of diet						
		Pryidoxine	Biotin	Pantothenic acid	Riboflavin	Folic acid	Niacin	Thiamin
1	30	238	19.8	1080	565	85	4540	650
	90	225	22.0	920	454	87	4700	690
	180	226	20.8	1120	484	109	4170	660
2	30	239	21.1	990	590	134	5680	1170
	90	242	21.3	940	545	109	5700	1300
	180	231	20.4	1060	588	134	4990	1270
2-M[1]	180	231	19.9	1090	573	117	4850	1300
3	30	239	21.1	970	490	113	4540	530
4	30	222	22.6	980	609	125	4540	630
11	30	217	17.4	870	454	55	3450	430
	90	183	20.9	830	343	68	3600	430
	180	179	16.3	980	399	68	2860	470

[1]Meal of diet No. 2 not pelleted.

acid than the *S. cerevisiae* diet (No. 1).

In order to determine the effect of prolonged storage on B-vitamin content, diets Nos. 1 and 2 were assayed 30, 90 and 180 days after storage at room temperature. Except for some loss in niacin, no appreciable destruction of vitamins was noted (Table 3). Pelletization of diet No. 2 did not effect any loss in B-vitamins of the mixed meal used in the diet.

Intake of Vitamins by Trout and Effects of Vitamins on Growth

Analyses of experimental diets for B-complex vitamins permitted calculation of daily intake of each vitamin by experimental lots of rainbow trout. Milligrams of vitamin fed per day per kilogram of trout, as shown in Table 4, met the tentative daily requirements, published by Halver (1954), only for thiamin and biotin. The enrichment of the control diet with the yeasts raised the thiamin intake beyond the requirement level. Supplementation with 15-percent *S. cerevisiae* yeast, (diet No. 10) increased the niacin intake to within requirement limits; however, this diet supplied less folic acid than 15-percent *C. utilis* (diet No. 9). In most cases, the daily feeding rate of the experimental diets needed to be at least doubled, and the rate of the control diet tripled, in order that the requirements reported by Halver be met. Because avitaminosis apparently did not occur, perhaps the requirements, as published, exceed the actual needs of the trout.

Table 4. *Comparison of vitamin intake by rainbow trout fed experimental diets at a rate of 2.1 percent of body weight per day and tentatively establishd daily requirement.*

Vitamin[1]	Diet number							Daily requirement[2]
	1	2	3	4	9	10	11	
Thiamin	0.30	0.54	0.25	0.29	0.22	0.66	0.19	0.15-0.19
Riboflavin	0.23	0.25	0.21	0.25	0.26	0.36	0.20	0.44-0.68
Niacin	2.0	2.5	2.0	2.1	2.8	3.7	1.4	3.0 -4.1
Pantothenic acid	0.44	0.43	0.41	0.43	0.48	0.68	0.37	0.97-1.25
Pyridoxine	0.10	0.11	0.11	0.10	0.13	0.13	0.08	0.23-0.25
Biotin	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01-0.03
Folic acid	0.04	0.05	0.06	0.05	0.11	0.05	0.03	0.15-0.18

[1]Vitamin levels are expressed as milligrams of vitamin fed per day per kilogram of trout.
[2]After Halver (1954)

Stimulation of growth by the different kinds and amounts of yeast was measured by weight gained. The cumulative percentage of gain by paired lots of trout on each diet is shown in Table 5. Superior growth was evidenced by all lots receiving a yeast supplemented diet. By analysis of variance, differences in growth obtained with 4 percent, 8 percent and 15 percent yeast were significant. Growth of trout was stimulated most by supplementation with 8 percent yeast. With the exception of 4-percent

feed grade *C. utilis,* all yeasts gave similar benefits to growth when used in the diet at the same level. The difference between growth on diet No. 3 and growths on other 4-percent yeast diets was statistically significant.

Effect Of Yeasts On Food Conversion Ratios

Utilization of the pelleted diets was measured in terms of conversion ratio: pounds of food fed divided by pounds of fish gained. Conversion ratios for the 18-week experimental period, as shown in Table 6, were 1.93 for the control diet, ranged from 1.71 to 1.78 for 4-percent yeast diets; 1.63 to 1.71 for 8 percent yeasts and 1.71 to 1.74 for 15 percent yeasts. By analysis of variance, differences in conversion ratios between the yeast diets and control diet were significant, but differences had with kinds and percentages of yeast were not significant; all levels and types of yeast were equally effective in improving conversion.

Table 5. *Growth expressed as percentage gain in weight for rainbow trout fed experimental diets containing different kinds and amounts of dried yeast for 18 weeks.*

Diet number	Percentage of yeast in diet	Total percentage gain in weight per lot		Mean percentage gain of two lots	Mean percentage mortality of two lots
		A	B		
1	4	145.6	151.0	148.3	2.7
2	4	147.2	149.1	148.2	3.0
3	4	139.0	140.4	139.7	1.2
4	4	148.2	148.0	148.1	2.3
5	8	156.1	159.5	157.8	2.0
6	8	149.2	164.9	157.1	3.8
7	8	158.8	152.7	155.8	2.8
8	8	158.0	160.7	159.3	3.2
9	15	155.5	150.0	152.8	2.5
10	15	154.9	150.0	152.5	4.5
11	0	125.3	129.0	127.2	2.3

Indexes of Well-Being

Mortality

The mean percentages in mortality, as given in Table 5, for the 18-week period were low. The higher mortalities in lots receiving diet Nos. 6, 8 to 10 resulted when frogs lodged in the faucets supplying water to these troughs. In other cases, most dead trout were deformed (lordosis) or runts. Losses of fish always increased after weighing. The conclusions are drawn, therefore, that no disease of importance occurred and that no marked reduction in mortality resulted from feeding yeast fortified diets.

Hemoglobin, Liver Fat and Biotin

Experimental feeding of a single lot of trout on each diet was continued beyond the 18-week limit of the original experiment. After being fed for 33 weeks, three to five trout were randomly selected from each lot and hemoglobin was measured. Average hemoglobin concentrations were 7.7 grams per 100 cubic centimeters of blood for the control lot; 8.5 to 10.4 for the 4-percent yeast fed lots, 7.5 to 8.2 for the 8 percent

yeasts and 7.9 to 8.6 for the 15 percent yeasts. There were no observed relationships between kinds of yeast fed and hemoglobin values. All trout receiving the test diets were borderline anemia cases when compared to normal values for trout of 10 to 13 grams of hemoglobin per 100 cubic centimeters of blood.

Fatty infiltration of the liver was a pathological condition that could be readily identified by gross inspection. Of 40 trout killed in each experimental lot, fatty livers were found in 2 to 8 fish per lot. Ten normal livers and five fatty livers from trout on diet No. 3 were analyzed for fat. The normal livers had an average weight of 3.22 grams and averaged 3 percent fat, while necrotic livers weighed 5.04 grams and averaged 6.3

TABLE 6. *Conversion ratios calculated as pounds of food fed per pound gain in weight for rainbow trout fed dry pelleted diets containing varied amounts of dried yeast for 18 weeks.*

Diet number	Percentage of yeast in diet	Conversion ratios of duplicated lots of trout		Mean conversion ratio of lots
		A	B	
1	4	1.77	1.74	1.76
2	4	1.75	1.73	1 74
3	4	1.77	1.79	1.78
4	4	1.67	1.74	1.71
5	8	1.69	1.57	1.63
6	8	1.75	1.67	1.71
7	8	1.69	1.71	1.70
8	8	1.66	1.65	1.66
9	15	1.69	1.72	1.71
10	15	1.73	1.74	1.74
11	0	1.95	1.90	1.93

TABLE 7. *Effect of dried yeast on biotin content of livers of rainbow trout fed for 33 weeks.*

Yeast supplement	Percentage of diet	Number of livers pooled	Average micrograms of biotin per gram of liver
S. cerevisiae	4	11	1.15
	8	10	1.00
	15	10	1.42
C. utilis food grade	4	11	1.27
	8	9	1.18
C. utilis feed grade	4	9	1.36
	8	10	1.30
	15	10	1.46
C. utilis high thiamin grade	4	10	1.33
	8	10	1.27
Control (no yeast)	—	10	1.40

percent fat. There was no correlation of liver necrosis with kind or amount of yeast in the diet.

Liver analyses indicated that diets fortified with 15 percent yeast effected the greatest storage of biotin (Table 7). The biotin contents of samples composed of 9 to 11 livers were 1.40 micrograms per gram of liver for the control diet, a range from 1.15 to 1.36 for 4 percent yeasts, from 1.00 to 1.30 for 8 percent yeasts and 1.42 and 1.46 for 15 percent yeasts. At similar levels, diets with *C. utilis* promoted higher storage levels of biotin than those containing *S. cerevisiae*. Phillips, *et al.*, (1951) found that *S. cerevisiae* yeast was more effective than the *C. utilis* yeast in increasing storage of biotin in brown trout livers. Since the control diet gave high liver levels of biotin and 8-percent yeast diets low levels, it is probable that growth rate as well as diet content of biotin determined the storage levels. All diets adequately protected the trout against "blue-slime" disease.

Condition of Trout

At the end of the 18-week test period, a 25-percent random sample of trout in each lot was measured. The individuals were weighed on a dietetic gram scale and total length taken in inches. The coefficient of condition (R) was calculated from the formula:

$$\text{Coefficient of Condition (R) equals } \frac{10W}{TL^3}$$

where: W is weight in grams and TL is total length in inches. Hatchery trout normally have a condition factor in the range 1.65 to 2.0. All yeast fortified diets produced trout whose coefficients ranged from 1.80 to 1.86. The control diet had trout whose mean coefficient was 1.73. These values indicated that the trout were not overfed and were in satisfactory physical condition.

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STRUCTURE AND GROWTH OF SCALES OF YELLOW PERCH OF GREEN BAY

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ABSTRACT

The appearance of the scales of yellow perch differs with the location on the fish's body. Comparison of scales of Green Bay perch taken above and below the lateral line reveals the former to have more sharply defined circuli and to exhibit fewer false annuli and less of the shading that impedes accurate assessment of age.

Estimates of age from modes in length-frequency distributions and from scale readings were the same for age-groups O, I, and II. Older age groups could not be detected in length distributions, but the similarity of all annuli makes it acceptable to conclude that the annulus is in fact a year-mark at ages beyond the II group.

Scales of yellow perch may exhibit new growth in the latter part of May whereas others may not have started growing even in late July. The time of annulus formation varies with calendar year, with age (new growth starts earlier in the younger fish), and possibly with locality. Ages usually can be read from scales collected during the period of annulus formation, but occasionally difficulties are encountered.

For larger yellow perch the relation between fish length and the radius of key scales was described by a straight line with a 2-inch intercept on the length axis when the scales were taken above the lateral line and by a straight line through the origin when the scales came from below the lateral line. Lengths calculated from both relations were inaccurate for small fish. Tables of corrections are given, based on the body-scale curves for small perch.

The body-scale relations (determined from the same key scale) were similar for Lake Erie and Saginaw Bay perch but both differed sharply from the relation in the Green Bay populations.

Good procedure requires high consistency in the field as to the point on the fish's body from which scale samples are taken and also a careful determination of the body-scale relation in each population studied.

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Introduction

The present paper is another in a series arising from a cooperative study of the Green Bay fisheries initiated in 1948 by the Fish and Wildlife Service and the Wisconsin Conservation Department. Although the Green Bay program has been concerned with various aspects of the fisheries, particular emphasis has been placed on the fishery for yellow perch *(Perca flavescens)*. A statement of the Green Bay perch problem and of changes of regulations based on early findings was given by Hile (1953). Other papers on Green Bay perch dealt with tagging (Joeris, 1953) and movements (Mraz, 1952).

The purposes of this publication are to submit evidence on the validity of the annulus as a true year-mark on the scales of yellow perch in Green Bay, to record information on the time of annulus formation in relation to the determination of age of summer-caught fish, and to show the relationship between fish length and the scale radius of "key" scales from the general areas from which scale samples were removed—in short to establish methods for use in further and detailed studies of regional differences and fluctuations in the perch stocks of Green Bay.

The earlier investigators of the age and growth of yellow perch in the Great Lakes (Harkness, 1922; Jobes, 1933; Hile and Jobes, 1941 and 1942) assumed the validity of the annulus as a year-mark. In his 1952 paper, however, Jobes gave information in support of the dependability of scale readings for yellow perch of Lake Erie. The earliest calculations of past growth from scale measurements (Jobes, 1933—Harkness, 1922, determined ages only) were made by direct proportion. Later calculations for perch of Saginaw Bay (Hile and Jobes, 1941) and Lake Erie (Jobes, 1952) were based on body-scale curves (key scales employed). Because they lacked materials for study of the body-scale relationship in the yellow perch of Green Bay, Hile and Jobes (1942) applied the curve they had derived for Saginaw Bay fish; as will be seen later, the results were not entirely satisfactory.

Investigators of the growth of yellow perch outside the Great Lakes mostly have given only the average sizes of age groups. Schneberger (1935) made direct-proportion calculations of length from measurements of scales of perch from three lakes of northeastern Wisconsin. Carlander (1950) described the body-scale relation of perch from Lake of the Woods with two conic-section parabolas.

Materials and Methods

The materials have been selected from extensive collections made in a continuing study of the yellow perch of Green Bay—life history, movements, fluctuations, regional differences, . . .

The 4,070 fish used to illustrate the length-frequency distribution of age-groups (Table 1, see also Fig. 1) were collected with a 42-foot otter trawl, 8 feet deep in the body of the net and 6 feet throughout the wings.

FIGURE 1.—Green Bay region.

The mesh size (extension measure) was 1 inch in the body and wings and 1/2 inch in the cod end. These three samples are typical of those obtained in trawling operations with the same or similar gear that took a total of more than 12,000 yellow perch.

The individual samples of yellow perch for the study of the body-scale relation (Table 1) were mostly small in order that the entire collection might cover a sufficient range of time and locality to bring out possible variability of the relation. A "key" scale was taken from each fish of each sample—the scale in the second row above the lateral line that fell immediately below the insertion of the first dorsal spine. Key scales from below the lateral line were obtained from the samples of May 27, 1955,

TABLE 1—*Material used for study of the body-scale relationship and length-frenquency distribution of age groups of perch in Green Bay.*

Use of material, gear, and mesh[1]	Date	Location	Number of fish
Length-frequency distribution			
Trawl ..... ½	Oct. 22, 1952	Suamico	1,681
Trawl ..... ½	Oct. 26, 1952	Fayette	670
Trawl ..... ½	Oct. 31, 1953	Fayette	1,719
Body-scale relationship above lateral line			
Wire trap ..... ¾	July 18, 1951	Sturgeon Bay	80
Trap net 2½	Aug. 20, 1951	Sturgeon Bay	15
Pound net 1½	Aug. 22, 1951	Escanaba	47
Dip net ..... ¼	Aug. 29, 1951	Gills Rock	5
Wire trap 1	Sept. 4, 1951	Sturgeon Bay	38
Wire trap ..... ½	Sept. 6, 1951	Gills Rock	4
Wire trap 1	Sept. 10, 1951	Sturgeon Bay	63
Wire trap ..... ¾	Sept. 24, 1951	Sturgeon Bay	34
Fyke net 2⅜	Sept. 25, 1951	Marinette	31
Seine ..... ¼	Sept. 29, 1951	Gills Rock	2
Fyke net 2⅜	Oct. 9, 1951	Suamico	132
Trap net 2	Oct. 9, 1951	Escanaba	8
Fyke net 2⅜	Oct. 10, 1951	Marinette	170
Seine ..... ¼	Oct. 15, 1951	Sturgeon Bay	1
Dip net ..... ¼	Dec. 27, 1951	Green Bay	56
Pound net 1¾	Jan. 22, 1952	Escanaba	75
Trap net 1	May 1, 1952	Sturgeon Bay	23
Fyke net 2	July 3, 1952	Sturgeon Bay	76
Fyke net 2⅜	Oct. 26, 1952	Escanaba	20
Fyke net 2⅜	Nov. 7, 1952	Marinette	23
Body-scale relationship above and below lateral line			
Fyke net 2⅜	May 27, 1955	Suamico	274[2]
Trawl 1½	June 5, 1956	Suamico	10
Seine ..... ¼	June 7, 1956	Gills Rock	38

[1]All mesh sizes are extension measure in inches with the exceptions of wire traps, dip nets, and seines in which bar measurements are given.

[2]Fish in this collection were also used in the comparison of calculated growths from above and below the lateral line.

and June 5 and 7, 1956. This key scale came from the third row below the lateral line directly beneath the sixth spine of the dorsal fin; it is the same key scale that was used by Hile and Jobes (1941) and by Jobes (1952). The reason for the use of two series of key scales is explained in later discussions. Total lengths of all fish were measured on a board and recorded to the nearest 0.1 inch.

The key scales of the samples of July 18, 1951, through November 7, 1952, and June 5 and 6, 1956, were mounted on glass microscope slides in the glycerin-gelatine medium described by Van Oosten (1929). Key scales of the 1955 sample were impressed on cellulose acetate, 0.020 or 0.040 inch thick, by a roller press similar to the one described by Smith (1954). Comparisons of the lengths of key scales (from above the lateral line) of fish of corresponding size as determined from mounts and impressions gave no evidence that method of preparation had any effect on the estimation of scale size. This observation is in agreement with that of Butler and Smith (1953).

The length of each key scale was measured at the magnification x 43 from the center of the focus to the edge of the sculpturing along the middle of the interradial space most nearly collinear with the focus. This measurement was made with a vernier caliper and recorded to the nearest 0.01 inch. Defective scales—regenerated, partially resorbed, or otherwise abnormal—were excluded. Altogether, the key-scale collections included 40 fish with unusable scales; these fish were excluded from the listing of Table 1. The scale length of each fish and accompanying data on fish length, sex, age, and date and locality of collection were punched on IBM cards to facilitate analysis.

The collections selected to show the time of annulus formation in various calendar years are listed in Table 5.

Ages are given in terms of completed years of life. A fish in its first year of life belongs to age-group O, one in its second year to age-group I. . . . Following the recommendation of Hile (1948), each fish is considered to pass into the next higher age group on January 1. Under this convention a "virtual" annulus is accredited at the edge of the scale from the first of the year to the time the annulus is actually formed.

The Yellow Perch Scale

The scales of yellow perch are typically ctenoid, deeply crenulated, and strongly imbricated. According to the description and diagram of Pycha and Smith (1955), scale pockets first appear in the peduncular region at a fish length of about 20 millimeters. Scale formation proceeds anteriorly along the lateral line and dorsally and ventrally from that line. Some scales are imbricated posteriorly along the lateral line in fish as short as 22 millimeters, and by the time the length has reached 35 millimeters the scales are imbricated over most of the body. This last point was verified by observations on Green Bay perch.

TABLE 2.—*Length-frequency distribution of age groups of yellow perch taken in small-mesh trawls off Fayette, Michigan October 31, 1953.*

[Totals are given for the sexes combined and for the entire collection from which the scale collection was drawn.]

Total length (inches)	Males						Females						Sexes combined	
	0	I	II	III	IV	Total	0	I	II	IV	V	Total	Scale sample	Entire catch
2.2-2.3	..	..	..	..	..	..	..	..	..	..	..	..	..	10
2.4-2.5	4	..	..	..	..	4	4	..	..	..	..	4	8	39
2.6-2.7	6	..	..	..	..	6	7	..	..	..	..	7	13	62
2.8-2.9	11	..	..	..	..	11	15	..	..	..	..	15	26	123
3.0-3.1	18	..	..	..	..	18	10	..	..	..	..	10	28	157
3.2-3.3	17	..	..	..	..	17	7	..	..	..	..	7	24	169
3.4-3.5	2	..	..	..	..	2	2	..	..	..	..	2	4	75
3.6-3.7	5	..	..	..	..	5	1	..	..	..	..	1	6	38
3.8-3.9	..	..	..	..	..	..	3	..	..	..	..	3	3	15
4.0-4.1	..	..	..	..	..	..	1	..	..	..	..	1	1	2
4.2-4.3	..	3	..	..	..	3	..	1	..	..	..	1	4	7
4.4-4.5	..	3	..	..	..	3	..	5	..	..	..	5	8	21
4.6-4.7	..	11	..	..	..	11	..	6	..	..	..	6	17	44
4.8-4.9	..	11	..	..	..	11	..	12	..	..	..	12	23	77
5.0-5.1	..	17	..	..	..	17	..	15	..	..	..	15	32	112
5.2-5.3	..	8	3	..	..	11	..	14	..	..	..	14	25	136
5.4-5.5	..	1	1	..	..	2	..	6	..	..	..	6	8	107
5.6-5.7	..	..	4	..	..	4	..	6	1	..	..	7	11	65
5.8-5.9	..	..	6	..	..	6	..	1	1	..	..	2	8	68
6.0-6.1	..	..	8	..	..	8	..	..	7	..	..	7	15	80
6.2-6.3	..	..	6	..	..	6	..	1	10	..	..	11	17	65
6.4-6.5	..	..	3	..	..	3	..	..	4	..	..	4	7	44
6.6-6.7	..	..	3	1	..	4	..	..	4	..	..	4	8	55
6.8-6.9	..	..	..	..	..	..	..	..	1	..	..	1	1	44
7.0-7.1	..	..	..	1	..	1	..	..	2	..	..	2	3	17
7.2-7.3	..	..	..	..	1	1	..	..	1	..	..	1	2	17
7.4-7.5	..	..	..	..	1	1	..	..	..	..	..	..	1	17
7.6-7.7	..	..	..	..	..	..	..	..	..	..	..	..	..	16
7.8-7.9	..	..	..	1	1	2	..	..	..	..	..	..	2	8
8.0-8.1	..	..	..	..	1	1	..	..	..	..	..	..	1	3
8.2-8.3	..	..	..	..	1	1	..	..	..	1	..	1	2	4
8.4-8.5	..	..	..	..	..	..	..	..	..	1	..	1	1	5
8.6-8.7	..	..	..	..	..	..	..	..	..	..	..	..	..	6
8.8-8.9	..	..	..	..	1	1	..	..	..	1	..	1	2	3
9.0-9.1	..	..	..	..	..	..	..	..	..	2	1	3	3	4
9.2-9.3	..	..	..	..	1	1	..	..	..	1	..	1	2	2
9.4-9.5	..	..	..	..	..	..	..	..	..	..	1	1	1	1
9.6-9.7	..	..	..	..	..	..	..	..	..	..	..	..	..	..
9.8-9.9	..	..	..	..	..	..	..	..	..	..	..	..	..	..
10.0-10.1	..	..	..	..	..	..	..	..	..	1	..	1	1	1
Number.....	58	54	34	3	7	161	50	67	31	7	2	157	318	1,719
Average length	3.0	4.8	6.0	7.1	8.2	..	3.0	5.1	6.3	9.0	9.2	..	..	..

On fully scaled yellow perch the appearance of the scale varies from one body region to another, and with this variability are associated important differences in the clarity of the markings employed for age determination. Perch scales collected from Green Bay before June 1950 were taken below the lateral line in the area of the second key scale defined in the preceding section. Beginning in June 1950 the scales were taken from the key area above the lateral line. Comparisons of scales from above and below the lateral line of the same fish (Fig. 2) illustrate differences between the two areas and justify a change in the point of removal of scales.

FIGURE 2.—Comparison of perch scales from two positions on the same fish, above lateral line (at left) and below lateral line (at right). Length of fish, 7.4 inches; age-group III.

The principal advantages of the scales from above the lateral line over those from below the lateral line may be summarized as follows:

1. Scales above the lateral line are relatively small and thin, and hence transmit light readily to give a clearly visible image. This advantage over scales below the lateral line grows increasingly important as the fish become larger.

2. The scales above the lateral line have the more sharply defined circuli. They are seldom broken or irregular. On scales below the lateral line, circuli are often "wavy" and commonly are interrupted and fused to neighboring circuli to give branched structures.

3. "Shading"—light and dark bands that bear no fixed relation to annuli—is less frequent and less pronounced on scales above the lateral line. The scale from a VI-group fish in Figure 4 gives an example of clear markings at a relatively advanced age. On scales below the lateral line this shading together with reduced light transmission can make the scales of the larger, older fish most difficult to read.

4. Accessory checks or "false annuli" are less frequent and less pronounced on the scales above the lateral line.

The single disadvantage in scales above the lateral line is the occasionally weak definition of the first annulus. With experience, errors from this difficulty can be avoided.

The differences between scales above and below the lateral line are probably of greater consequences in the slowly growing Green Bay stock than in many, possibly most, other populations in the Great Lakes. Determination of age from scales of yellow perch of this bay must be recognized as difficult. In the rapidly growing perch studied by Hile and Jobes (1940) and Jobes (1953) scales below the lateral line seem to have been fully satisfactory.

Validity of the Annulus

The principal evidence offered here on the validity of the annulus as a year-mark on the scales of yellow perch of Green Bay is the agreement between ages as read from scales and as estimated from modes in the length-frequency distributions of large samples of fish[1]. Although this method is applicable only to those younger age groups that stand out in a general length distribution, it has the great advantage of being direct. Since the appearance of the annuli at the lesser ages is similar to that of the later annuli of older fish, a reasonable extension of conclusions based on the younger fish is acceptable. As the study of Green Bay perch is continued, additional evidence on the validity of the annulus almost surely will accumulate.

All of the length-frequency distributions of yellow perch captured on Green Bay by small-mesh otter trawls were multi-modal (Tables 2, 3, and 4; Figs. 5, 6, and 7.) The length distributions of both male and female perch of the October 1953 sample from Fayette, Michigan, exhibited three distinct modes that strongly suggest the presence of three age-groups[2]. This view was supported fully by the scale readings. For males the modes (from length frequencies, original data compiled by 0.1 inch groups) and mean lengths (from scale readings) were: age-group O, 3.1 and 3.0 inches; age-group I, 5.1 and 4.8 inches; age-group II, 6.1 and 6.0 inches. For the females the modes and means were: age-group 0, 2.9 and 3.0 inches; age-group I, 5.1 and 5.1 inches; age-group II, 6.3 and 6.3 inches. This close agreement between estimates from length distributions and from scales (see Fig. 4 for typical scales from fish of age-groups O, I and II) leaves no doubt that scales of young of the year lacked annuli

[1]For reviews of the various kinds of evidence that have been offered in support of the validity of scale readings see papers by Van Oosten (1929) and Hile (1941).

[2]Frequency distributions are given in the tables for the sexes combined (scale sample) and for the entire catch to demonstrate that the subsamples from which scales were taken were satisfactorily representative.

TABLE 3.—*Length-frequency distribution of age groups of yellow perch taken in small-mesh trawls off Fayette, Michigan October 22, 1952.*

[Totals are given for the sexes combined and for the entire collection from which the scale collection was drawn.]

Total length (inches)	Males							Females						Sexes combined	
	0	I	II	III	IV	V	Total	0	I	II	III	IV	Total	Scale sample	Entire catch
2.0-2.1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1
2.2-2.3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
2.4-2.5	2	..	..	..	..	..	2	4	..	..	..	..	4	6	16
2.6-2.7	3	..	..	..	..	..	3	5	..	..	..	..	5	8	23
2.8-2.9	4	..	..	..	..	..	4	4	..	..	..	..	4	8	20
3.0-3.1	1	..	..	..	..	..	1	1	..	..	..	..	1	2	9
3.2-3.3	1	..	..	..	..	..	1	1	..	..	..	..	1	2	5
3.4-3.5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2
3.6-3.7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
3.8-3.9	..	..	..	..	..	..	..	..	1	..	..	..	1	1	2
4.0-4.1	..	..	..	..	..	..	..	..	1	..	..	..	1	1	7
4.2-4.3	..	3	..	..	..	..	3	..	1	..	..	..	1	4	17
4.4-4.5	..	9	..	..	..	..	9	..	5	..	..	..	5	14	40
4.6-4.7	..	9	..	..	..	..	9	..	9	..	..	..	9	18	58
4.8-4.9	..	8	..	..	..	..	8	..	13	..	..	..	13	21	51
5.0-5.1	..	11	..	..	..	..	11	..	11	..	..	..	11	22	41
5.2-5.3	..	4	..	..	..	..	4	..	7	..	..	..	7	11	18
5.4-5.5	..	1	..	..	..	..	1	..	..	..	..	..	..	1	9
5.6-5.7	..	1	1	..	..	..	2	..	..	..	..	..	..	2	7
5.8-5.9	..	1	1	2	..	..	4	..	..	1	..	..	1	5	6
6.0-6.1	..	..	3	..	..	..	3	..	..	..	..	..	..	3	7
6.2-6.3	..	..	3	3	..	..	6	..	..	1	1	..	2	8	13
6.4-6.5	..	..	4	13	..	..	17	..	..	1	1	..	2	19	26
6.6-6.7	..	..	..	19	..	..	19	..	..	1	..	..	1	20	34
6.8-6.9	..	..	1	31	..	..	32	..	..	..	2	..	2	34	43
7.0-7.1	..	..	..	17	1	..	19	..	..	1	..	..	1	28	28
7.2-7.3	..	..	..	19	..	1	20	..	..	..	1	1	2	21	30
7.4-7.5	..	..	..	12	3	..	15	..	..	..	12	..	12	27	44
7.6-7.7	..	..	..	7	1	..	8	..	..	..	11	..	11	11	26
7.8-7.9	..	..	..	..	2	..	2	..	..	1	9	..	10	19	22
8.0-8.1	..	..	..	3	1	..	4	..	..	..	3	..	3	12	12
8.2-8.3	..	..	..	1	2	..	3	..	..	..	6	..	6	7	10
8.4-8.5	..	..	..	..	..	..	..	..	..	..	4	..	4	9	8
8.6-8.7	..	..	..	..	..	..	..	..	..	..	4	1	5	4	9
8.8-8.9	..	..	..	..	1	..	1	..	..	..	4	1	5	5	9
9.0-9.1	..	..	..	..	..	..	..	..	..	..	6	2	8	6	9
9.2-9.3	..	..	..	..	1	..	1	..	..	..	..	..	..	8	10
9.4-9.5	..	..	..	..	..	..	..	..	..	..	1	..	1	1	2
9.6-9.7	..	..	..	..	..	..	..	..	..	..	..	..	..	1	1
9.8-9.9	..	..	..	..	..	..	..	..	..	..	2	..	2	..	..
10.0-10.1	..	..	..	..	..	..	..	..	..	..	..	..	..	2	2
10.2-10.3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1
10.4-10.5	..	..	..	..	..	1	1	..	..	..	..	..	..	..	..
Number....	11	47	13	127	12	2	212	15	48	6	67	5	141	1	1
Aver. lgth..	2.8	4.9	6.3	9.1	8.0	8.8	..	2.8	4.9	6.7	8.0	8.6	..	353	670
														..	..

and that the annuli on the scales of fish assigned to age-groups I and II were in fact year-marks. In view of the similarity of these earlier, valid annuli to the later ones on presumably older fish (for example, age-groups III and VI, Fig. 4) it appears safe to assume that these later annuli also are year-marks.

The October 1953 sample from Fayette was peculiarly well suited to show agreement between ages as estimated from modes and as read from scales because of the scarcity of III-group fish (the females included no members of this age group). Had the III group been better represented in comparison with age-group II, the mode for perch of the latter age would not have stood out so sharply in the general distribution. The importance of the relative numbers in age groups to the appearance of the length distribution is brought out by the data on the Fayette samples of October 1952 (Table 3; Fig. 6). Here age-group O (despite its limited representation) and age-group I appear as distinct modes in the length distribution of each sex. However, the third mode which, in the absence of other information, probably would be taken to represent age-group II was indicated by scale readings actually to represent the III groups.

This seeming conflict between length distribution and scale readings does not damage the argument as to the validity of the annulus as a year-mark. On the contrary, the 1952 and 1953 samples from Fayette, considered together, offer the strongest evidence of another type that scale readings are highly dependable. The poorly represented age groups, the II group of 1952 and the III group of 1953, both came from the 1950 hatch. Inasmuch as this year class was indicated to be extremely weak in two independent estimates made 1 year apart, we may conclude that its members laid down a single annulus during the year between samplings.

The third trawl sample, the one collected off Suamico, Wisconsin, in October 1952, serves principally to show a general similarity of length distributions in southern and northern Green Bay (Table 4; Fig. 7). In the Suamico collection, age-groups O and I stood out as distinct modes, but the II group did not, largely because of the presence of relatively good numbers of age-group III, the broad range of length in both age groups, and the small difference between their average lengths.

The evidence on the validity of annuli as year-marks does not warrant the conclusion that the scales of every fish are read correctly. Accessory checks or false annuli can occur which resemble the true annulus so closely as to deceive the investigator. Furthermore, the scales of some fish exhibit such a confused and irregular pattern as to make the actual age uncertain. Nevertheless, the general dependability of age determination from scales can be accepted and the method may be applied with a high level of confidence to the study of the life history of the yellow perch of Green Bay.

Time of Annulus Formation

The formation of annuli on the scales of a stock of fish ordinarily takes place over a considerable period of time—at least several weeks. The actual dates vary with species, among different stocks of the same species, and from year to year, and according to age within a single stock[3]. This variability can lead to difficulties in age determination in samples collected during the period of annulus formation. Usually it is possible to judge with confidence whether an individual fish has started the current season's growth, but if the period of annulus formation is long and if growth is slow or variable it may be difficult sometimes to judge whether the scale margin outside the last visible annulus represents exceptionally good growth in the current year (after completion of annulus) or relatively poor growth in the preceding year (annulus not yet completed). Hile (1941), for example, rejected a sample of rock bass *(Ambloplites rupestris)* taken from Nebish Lake, (Wisconsin) on July 5 and 6, 1930, because he could not decide for certain fish ". . . whether the band of growth represented growth made in 1930 subsequent to annulus formation or whether the 1930 annulus had not yet been formed . . .".

To estimate the length of time over which Green Bay yellow perch form annuli and especially to learn whether difficulties of age determination might exist similar to those described by Hile for the Nebish Lake rock bass, a tabulation was made of the incidence of new (current-season) growth on the scales of fish collected in spring and early summer. Before this material is discussed, some comments are needed on the course of early-season growth and on the criterion used for decision as to whether new growth had started. The first evidence of resumption of scale growth is seen in the broadening of the clear, unsculptured margin of the anterior field. The width of this margin is so variable, however, that it cannot provide a usable basis for decision. In the preparation of Table 5 a scale was considered to show new growth when at least one new circulus was completed across the anterior edge to make at least a start on the "line of discontinuity" which, when carried laterally to the posterior field, would constitute a completed annulus (Fig. 3). Although this criterion seemed the most satisfactory, its application is not without danger. It is possible that on a few scales the apparent "new growth" merely resulted from a check laid down near the end of the preceding season—a check that could be detected readily once the true annulus was completed. On the other hand, it does not seem desirable to hold that new growth has not started until the annulus is complete. Typically a considerable amount of growth has been made anteriorly by the time new growth first becomes visible in the postero-lateral field (Fig. 3).

[3]See Beckman (1943) for a review of the literature on annulus formation.

TABLE 4.—*Length-frequency distribution of age groups of yellow perch taken in small-mesh trawls off Suamico, Wisconsin October 22, 1952.*

[Totals are given for the sexes combined and for the entire collection from which the scale collection was drawn.]

Total length (inches)	Males					Females						Sexes combined	
	0	I	II	III	Total	0	I	II	III	IV	Total	Scale sample	Entire catch
2.4-2.5	..	..	..	..	..	..	..	..	..	..	..	..	1
2.6-2.7	..	..	..	..	..	..	..	..	..	..	..	..	..
2.8-2.9	3	..	..	..	3	1	..	..	..	..	1	4	8
3.0-3.1	5	..	..	..	5	10	..	..	..	..	10	15	33
3.2-3.3	5	..	..	..	5	13	..	..	..	..	13	18	70
3.4-3.5	3	..	..	..	3	8	..	..	..	..	8	11	58
3.6-3.7	..	..	..	..	..	4	..	..	..	..	4	4	25
3.8-3.9	..	..	..	..	..	..	..	..	..	..	..	..	8
4.0-4.1	..	..	..	..	..	..	..	..	..	..	..	..	..
4.2-4.3	..	1	..	..	1	..	..	..	..	..	..	1	3
4.4-4.5	..	2	..	..	2	..	1	..	..	..	1	3	12
4.6-4.7	..	10	..	..	10	..	4	..	..	..	4	14	32
4.8-4.9	..	20	..	..	20	..	18	..	..	..	18	38	126
5.0-5.1	..	29	..	..	29	..	20	..	..	..	20	49	237
5.2-5.3	..	11	3	..	14	..	24	..	..	..	24	38	235
5.4-5.5	..	5	..	..	5	..	4	..	..	..	4	9	163
5.6-5.7	..	1	2	..	3	..	1	1	..	..	2	5	91
5.8-5.9	..	2	2	..	4	..	1	4	..	..	5	9	49
6.0-6.1	..	..	7	1	8	..	1	..	..	..	1	9	43
6.2-6.3	..	..	11	2	13	..	..	4	..	..	4	17	55
6.4-6.5	..	..	4	5	9	..	..	1	..	..	1	10	63
6.6-6.7	..	..	6	5	11	..	..	1	..	..	1	12	66
6.8-6.9	..	..	6	4	10	..	..	3	1	..	4	14	83
7.0-7.1	..	..	..	7	7	..	..	3	..	..	3	10	72
7.2-7.3	..	..	..	3	3	..	..	..	2	1	3	6	40
7.4-7.5	..	..	..	2	2	..	..	2	2	..	4	6	47
7.6-7.7	..	..	..	1	1	..	..	..	1	..	1	2	24
7.8-7.9	..	..	..	..	..	..	..	..	1	..	1	1	12
8.0-8.1	..	..	..	1	1	..	..	..	..	..	..	1	7
8.2-8.3	..	..	..	..	..	..	..	..	..	..	..	..	10
8.4-8.5	..	..	..	..	..	..	..	..	..	..	..	..	4
8.6-8.7	..	..	..	..	..	..	..	..	1	..	1	1	1
8.8-8.9	..	..	..	..	..	..	..	..	..	..	..	..	1
9.0-9.1	..	..	..	..	..	..	..	..	..	..	..	..	..
9.2-9.3	..	..	..	..	..	..	..	..	..	..	..	..	..
9.4-9.5	..	..	..	..	..	..	..	..	..	..	..	..	1
9.6-9.7	..	..	..	..	..	..	..	..	..	..	..	..	..
9.8-9.9	..	..	..	..	..	..	..	..	..	..	..	..	1
Number	16	81	41	32	169	36	74	19	8	1	138	307	1,681
Average length	3.1	5.0	6.3	6.8	..	3.3	5.1	6.5	7.6	7.2	..	..	.

FIGURE 3.—Annulus formation on the scale of yellow perch. Current-season growth has not started on the scale at the left; the appearance is typical of scales collected in late fall or early spring. New growth has started on the scale at right; 3-4 circuli are visible anteriorly but the new annulus is not quite complete in the lateral fields.

The one April sample of yellow perch from Green Bay (April 30, 1951) included no fish that had started new growth (Table 5).

The May collections of 1949-1954 included a scattered few yellow perch (most in age-groups II and III) whose scales gave indication of new growth. In the nine samples obtained in those years the incidence of new growth ranged from nil in the two collections of May 21, 1954, to 5 percent in that of May 10, 1949. Some of these fish actually may have started to grow; on others the difficult marginal scale pattern may have been misinterpreted.

The 1955 sample differed from the May collections of earlier years in that a good majority (69 percent of the total; 20-100 percent in individual age groups) exhibited new growth. The incidence of new growth decreased from age-group II through age-group V, but increased slightly in the VI group. This early start most probably was caused by the exceptionally warm spring. According to records of the U.S. Weather Bureau the plus departures of the 1955 air temperature at Green Bay and Escanaba from monthly normals for April and May were:

City	*Departure from normal temperature (F°)*	
	April	*May*
Green Bay	7.1	2.4
Escanaba	7.3	3.8

Only three samples were collected in June. Two from Marinette (June 25, 1950, and June 2, 1953) included few fish whose scales exhibited new growth. In the sample from Garden (June 6. 1953) 39 percent had started to grow. The difference between the Marinette sample of June 2 and the Garden sample of June 6, suggests possible local vari-

TABLE 5.—*Percentage of yellow perch in the different age groups of various collections whose scales indicated that the current-season growth had started.*

[In parenthesis, number with new growth at left and number without new growth at right; gear of capture as follows: pound-net—April 30, 1951; otter trawl—May 31 and June 24, 1952—first sample May 21, 1954; fyke-net—all other samples.]

Date of Collection	Port	Age group I	II	III	IV	V	VI	VII	VIII	All ages
1949										
May 10	Suamico	..	..	7	2	3	0	..	..	5
		..	..	(7-94)	(1-63)	(1-37)	(0-3)	..	..	(9-197)
May 17	Suamico	..	..	20	0	0	0	0	..	4
		..	..	(3-12)	(0-22)	(0-34)	(0-11)	(0-2)	..	(3-81)
1950										
May 10	Suamico	..	..	9	0	0	0	0	..	2
		..	..	(5-52)	(0-108)	(0-48)	(0-8)	(0-4)	..	(5-220)
June 25	Marinette	..	..	14	8	0	..	..	..	4
		..	..	(1-6)	(3-34)	(0-57)	..	..	..	(4-97)
July 14	Suamico	..	100	67	[1]..	[1]..	..	..	..	[1]..
		..	(6-0)	(10-5)	..	..	..	..	..	..
1951										
April 30	Suamico	0	0	..	..	..	..	..	..	0
		(0-81)	(0-5)	..	..	..	..	..	..	(0-86)
May 10	Suamico	..	..	6	2	1	0	..	..	2
		..	..	(3-51)	(2-123)	(1-69)	(0-11)	..	..	(6-254)
July 18	Suamico	..	100	100	100	..	..	..	..	100
		..	(5-0)	(41-0)	(7-0)	..	..	..	..	(53-0)
1952										
May 31	Marinette	0	0	8	1	0	0	..	..	2
		(0-15)	(0-3)	(3-33)	(1-131)	(0-10)	(0-6)	..	..	(4-198)
July 24	Marinette	100	27	31	38	100	..	..	..	39
		(5-0)	(3-8)	(10-22)	(3-5)	(1-0)	..	..	..	(22-35)
1953										
May 26	Suamico	..	0	3	8	0	0	..	..	3
		..	(0-1)	(1-30)	(3-34)	(0-58)	(0-2)	..	..	(4-125)
June 2	Marinette	..	..	0	0	1	0	0	0	1
		..	..	(0-2)	(0-37)	(1-69)	(0-8)	(0-2)	(0-1)	(1-119)
June 6	Garden	..	..	100	44	17	0	..	..	39
		..	..	(1-0)	(44-57)	(2-10)	(0-5)	..	..	(47-72)
1954										
May 10	Marinette	..	50	0	0	0	0	..	..	1
		..	(1-1)	(0-59)	(0-16)	(0-58)	(0-11)	..	..	(1-145)
May 21	Suamico	0	0	0	0	0	..	..	..	0
		(0-2)	(0-81)	(0-61)	(0-3)	(0-5)	..	..	..	(0-152)
May 21	Suamico	..	..	0	0	0	0	0	0	0
		..	..	(0-77)	(0-31)	(0-36)	(0-11)	(0-11)	(0-1)	(0-167)
July 22	Marinette	..	100	100	100	100	100	..	..	100
		..	(9-0)	(79-0)	(14-0)	(23-0)	(6-0)	..	..	(131-0)
July 23	Suamico	..	100	100	100	100	..	..	..	100
		.	(58-0)	(86-0)	(5-0)	(5-0)	..	..	..	(154-0)
July 26	Garden	..	..	100	100	100	100	..	..	100
		..	..	(83-0)	(24-0)	(130-0)	(5-0)	..	..	(242-0)
1955										
May 27	Suamico	..	100	90	39	20	44	..	..	69
		..	(19-0)	(128-14)	(36-57)	(2-8)	(4-5)	..	..	(189-84)

[1]Age uncertain for most older fish.

ation in the time of onset of new growth. The Garden sample and the 1950 collection from Marinette indicated an earlier start of new growth among the younger than among the older fish.

All of the yellow perch had started current-season growth in four of the six July samples. These four collections were made from July 18 (Suamico, 1951) to July 26 (Garden, 1954). Only 39 percent, however, had begun to grow in the Marinette sample of July 24, 1952. The difference between the 1952 and 1954 collections from Marinette offers another example of annual variation in the date of onset of growth. The 1952 sample from Marinette exhibited no clear-cut relation between age and the start of growth.

The sample of July 14, 1950, requires special comment since it was the only one in which the assessment of age was difficult for a high percentage of the fish. In other samples the distribution of the width of the bands of marginal growth was such that only rarely was it difficult to decide whether the band represented current-season growth or the entire growth of the preceding season. Some errors may have been made, but surely they were few. It is believed that in the sample of July 14, 1950, the members of age-groups II and III were identified correctly, but among

TABLE 6.—*Scale radius* (S) *at different fish lengths* (L) *and variation of the body-scale ratio with increase of length for key scales above and below the lateral line.*

Total length (inches)	Above lateral line				Below lateral line			
	Number of fish	Average total length (inches)	Average scale radius (inches x 43)	L/S	Number of fish	Average total length (inches)	Average scale radius (inches x 43)	L/S
2.5-2.9	6	2.87	0.68	4.22	6	2.87	1.13	2.54
3.0-3.4	10	3.19	0.83	3.84	10	3.19	1.38	2.31
3.5-3.9	14	3.72	1.09	3.41	14	3.72	1.71	2.18
4.0-4.4	9	4.11	1.29	3.19	9	4.11	2.18	1.89
4.5-4.9	2	4.65	1.45	3.21	2	4.65	2.34	1.99
5.0-5.4	45	5.28	1.92	2.75	7	5.27	2.94	1.79
5.5-5.9	68	5.71	2.14	2.67	7	5.69	3.62	1.57
6.0-6.4	67	6.19	2.51	2.47	11	6.21	4.06	1.53
6.5-6.9	60	6.74	2.88	2.34	48	6.76	4.50	1.50
7.0-7.4	118	7.21	3.07	2.35	113	7.22	4.58	1.58
7.5-7.9	98	7.66	3.26	2.35	80	7.64	4.85	1.58
8.0-8.4	40	8.14	3.62	2.25	13	8.13	5.21	1.56
8.5-8.9	24	8.68	4.03	2.15	3	8.60	5.25	1.64
9.0-9.4	23	9.21	4.20	2.19	6	9.20	5.98	1.54
9.5-9.9	20	9.60	4.72	2.03	2	9.85	6.62	1.49
10.0-10.4	23	10.19	5.12	1.99	1	10.30	7.05	1.46
10.5-10.9	24	10.65	5.26	2.02	..			
11.0-11.4	18	11.16	5.43	2.06				
11.5-11.9	15	11.69	5.96	1.96				
12.0-12.4	8	12.10	6.04	2.00	..			
12.5-12.9	6	12.72	6.32	2.01	..			
13.0-13.4	6	13.13	6.30	2.08	..	..		
13.5-13.9	4	13.72	6.68	2.05	..	..		
14.0-14.4	2	14.00	6.10	2.30	..	..		

older fish the interpretation of marginal growth was uncertain on so many scales that separation into age-groups was inadvisable. No explanation can be offered now for this peculiarity of the sample.

Despite the variability in the data as to the start of growth of yellow perch in Green Bay, certain general statements can be made. Normally the scales of relatively few perch collected before the end of May give evidence of current-season growth, but in exceptional years (as 1955) a large percentage of the fish may be growing before the end of the month. Perch showing new growth may still be scarce in late June (only 3 percent on June 25, 1950) and good numbers may have started growth in early June (39 percent on June 6, 1953). All perch had started to grow in four of the collections made in the last half of July, but only 39 percent showed new growth in the Marinette collection of July 24, 1952. All perch collected in August (data not tabulated in Table 5) had completed annuli. The onset of the season's growth varies with age (is earlier in the younger fish), calendar year, and possibly with locality. Ages can be read with confidence from most scales collected during the period of annulus formation, but in the exceptional collection age determinations may be uncertain for many of the older fish (samples of July 14, 1950).

Body-Scale Relation

At the time the field station of Great Lakes Fishery Investigations was established at Sturgeon Bay, Wisconsin, in June 1950, only limited progress had been made on the study of materials collected from Green Bay in 1948, 1949, and May 1950. The urgency of keeping abreast of changing conditions in the Bay was so great that these earlier samples continued to be neglected during the next several years, while efforts were concentrated on the immediate study of current samples.

As part of the program that started in 1950, materials were collected for study of the relation between length of fish and the radius of key scales from the region above the lateral line from which scale samples were removed after May 1950. These collections were made July 18, 1951, to November 7, 1952 (Table 1). Because Hile and Jobes (1942) had applied the body-scale curve for perch from Saginaw Bay to the Green Bay fish, no key scales were collected from the region below the lateral line from which earlier scale samples had been removed. When the study of the 1948, 1949, and May 1950 materials was started it became obvious at once that the Saginaw Bay curve did not give satisfactory results with those Green Bay materials. Key scales from above and below the lateral line were accordingly obtained from samples collected May 27, 1955, and June 5 and 7, 1956.[4]

The scale samples collected on June 5 and 7, from fish with total length of 2.8 to 5.5 inches were applied to complete the lower portions of both curves.

[4]Key scales taken above the lateral line on May 27, 1955, were used to compare growth histories of the same fish as computed from measurements of scales from two locations on the body and for comparing estimates of scale size as determined from glycerin-gelatine mounts and from plastic impressions.

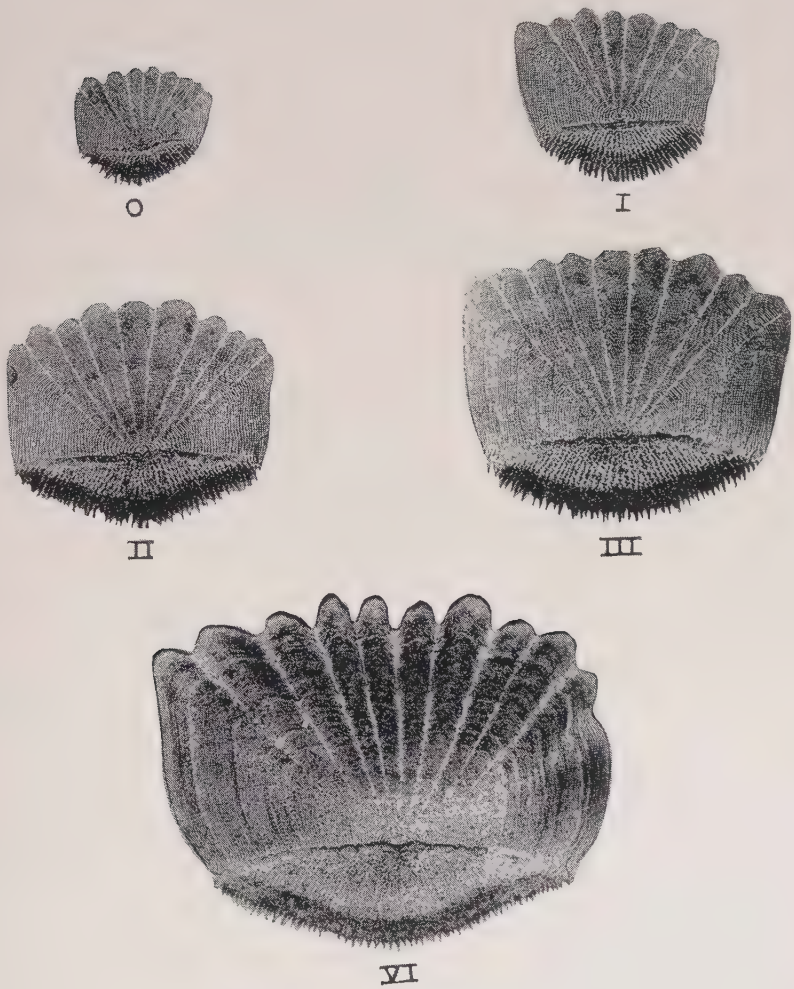

FIGURE 4.—Typical scales of yellow perch of age-groups O, I, II, III and VI.

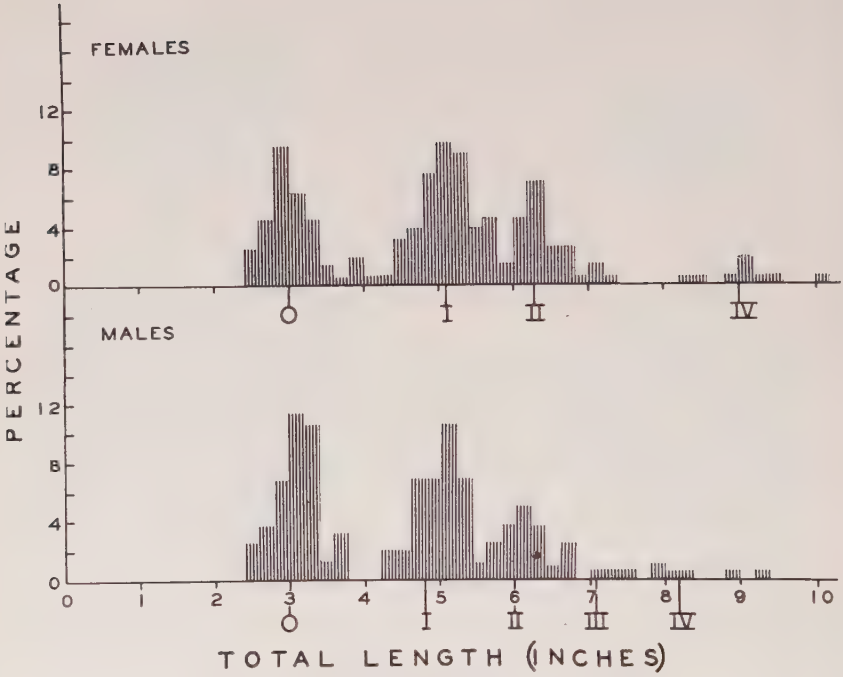

FIGURE 5.—Length distribution of yellow perch taken by trawl off Fayette, Michigan, October 31, 1953. Average lengths of age groups as read from scales are indicated.

KEY SCALES ABOVE THE LATERAL LINE

Preliminary analyses indicated that among fish of the same length, the radius of the scale did not vary significantly with age, sex, locality, or date of capture. All samples, therefore, were combined for further study of the body-scale relation. A graph of the average length of scales for 0.1-inch intervals of fish length (Fig. 8; these data are summarized by 0.5-inch intervals of length in Table 6) indicated the body-scale relation of yellow perch 4.0 to 14.0 inches long could be described by a straight line. The equation for this line, fitted by least squares, was

$$L = 1.980 + 1.687\ S$$

where L equals total length in inches, and S equals scale radius (x 43) in inches. For practical purposes the intercept may be taken as 2.0 inches.

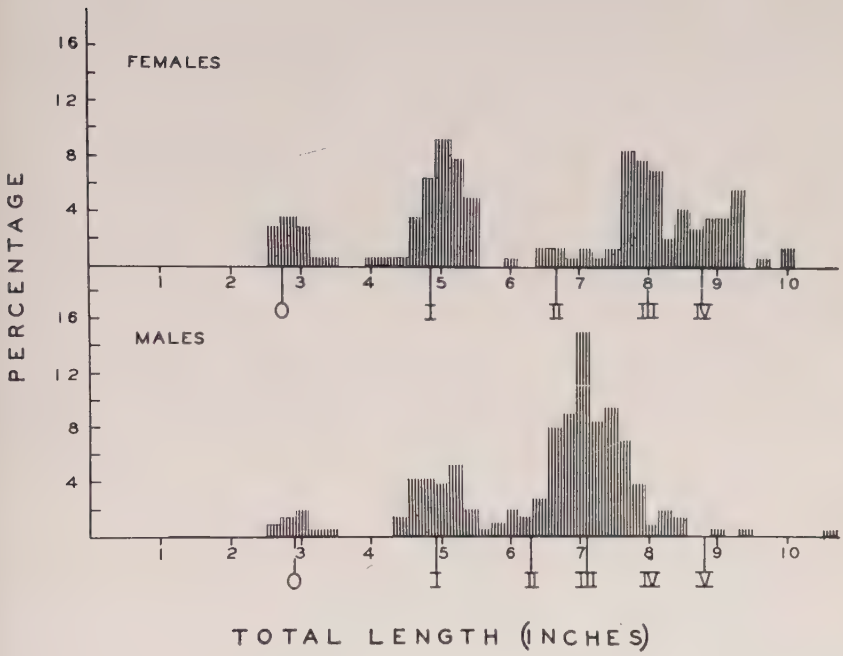

FIGURE 6.—Length distribution of yellow perch taken by trawl off Faye'te, Michigan, October 26, 1952. Average lengths of age groups as read from scales are indicated.

As may be seen from Figure 8 (upper curve), the straight line fitted the empirical data reasonably well over the 4.0- to 14.0-inch interval; at fish lengths less than 4.0 inches the lengths of scale radii were consistently greater than the values obtained from the equation. That part of the body-scale curve for fish less than 4 inches long was accordingly fitted by inspection.

The body-scale relation can be employed for the calculation of growth from scale measurements by the use of a formula and a table of corrections. In this procedure the lengths are first calculated from:

$$Ln = 2.0 + \frac{Lt - 2}{St} Sn$$

where Ln = calculated length at end of nth year,
Lt = total length at capture,
Sn = scale radius to nth annulus,
St = scale radius

Calculated lengths of 4.0 inches or greater can be accepted as computed. Calculated lengths less than 4.0 inches are overestimates that can be corrected by the use of Table 7. The corrections in this table, which were determined from the original graph of the body-scale curve, are the vertical distances between the dotted extension of the straight line (Fig. 8 upper curve) and the empirically fitted body-scale curve.

In actual practice the calculations of past growth were made nomographically. First, the body-scale relation was inscribed on a strip of transparent plastic in the manner described by Hile (1950). This strip was then substituted for the ruler in the nomograph devised by Joeris (1950). It was possible with this equipment to record the correct calculated lengths as the scales were measured.

Key Scales Below the Lateral Line

The original graph of the body-scale data for key scales from below the lateral line indicated that the relation for the larger fish could be described by a straight line passing through or near the origin, but that the relation deviated sharply from this line among the shorter fish. The view concerning the straight-line relation among the longer fish was supported by the values of the body-scale ration L/S which varied randomly (that is, without noticeable trend) at fish lengths greater than 5.4 inches (Table 6; see also Fig. 8, lower curve). For a straight line through the origin, of course, this ratio is constant.

The fitting of a straight line (by least squares) to the body-scale data (mean radii of scales, $\times$ 43, for 0.1-inch intervals of total length of fish) yielded the equation:

$$L = 0.127 + 1.522\ S$$

The intercept is so small that for practical purposes it can be ignored.

The body-scale curve for fish less than 5.5 inches long was fitted by inspection.

Calculations of past growth of fish from which scale samples had been removed below the lateral line were made by direct proportion. Cal-

culated lengths of 5.5 inches or longer were recorded as computed, but those smaller than 5.5 inches were underestimates. The corrections that were added to these shorter calculated lengths (Table 7) were determined by measurements of the original body-scale graph. A nomograph was not prepared since the collection of scale samples below the lateral line was abandoned after May 1950.

Growth Estimates from Two Different Body-Scale Curves

In order that a comparison could be made of the calculated growth of the same fish as determined from each of the body-scale curves, a series of paired scale samples was removed from the Suamico collection of May 27, 1955, one from above and the other from below the lateral line. A comparison of the calculated growth of these fish as determined from the two sets of scales (Table 8) indicates good agreement in all age groups. The maximum discrepancy of 0.10 inch occurred in the second year of life of the VI group. The mean disagreement for all calculated lengths was 0.03 inch (average of absolute values).

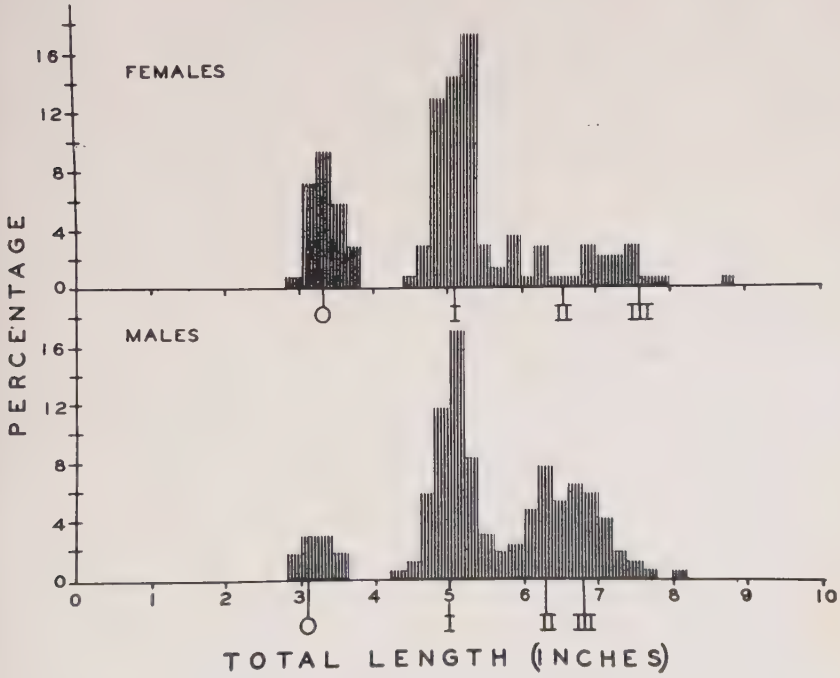

Figure 7.—Length distribution of yellow perch taken by trawl off Suamico, Wisconsin, October 22, 1952. Average lengths of age groups as read from scales are indicated.

For individual fish the discrepancy between the calculated lengths from scales above and below the lateral line seldom exceeded 0.2 inch. Th maximum disagreements occurred at the end of the second year of life where an occasional difference of 0.3 or 0.4 inch and one of 0.6 inch occurred.

TABLE 7.—*Corrections (inches) to be added or subtracted from the shorter lengths computed from straight lines to bring them into agreement with the emperically determined body-scale relation of small fish.*

Total length (inches)	Above lateral line	Below lateral line	Total length (inches)	Below lateral line
2.8	—0.30	0.97	4.2	0.76
2.9	—0.29	0.96	4.3	0.74
3.0	—0.28	0.95	4.4	0.70
3.1	—0.25	0.94	4.5	0.65
3.2	—0.22	0.93	4.6	0.61
3.3	—0.19	0.92	4.7	0.57
3.4	—0.16	0.91	4.8	0.51
3.5	—0.14	0.90	4.9	0.44
3.6	—0.10	0.88	5.0	0.36
3.7	—0.07	0.86	5.1	0.30
3.8	—0.04	0.84	5.2	0.24
3.9	—0.01	0.82	5.3	0.17
4.0	..	0.80	5.4	0.08
4.1	..	0.78	5.5	..

TABLE 8.—*Comparison of calculated total lengths (inches) as determined from scales taken above and below the lateral line.*

[Based on the collection of May 27, 1955. Ages were not determined for 2 of the 274 fish in the sample.]

Age group	Scale location	Number of fish	Length at capture	Calculated length at end of year of life					
				1	2	3	4	5	6
II	Above	19	6.63	3.88	6.21	..	..	..	..
	Below			3.93	6.21	..	..	..	..
III	Above	146	7.32	3.65	5.65	7.08	..	..	..
	Below			3.68	5.68	7.08	..	..	..
IV	Above	91	7.56	3.35	5.14	6.40	7.40	..	..
	Below			3.37	5.09	6.36	7.39	..	..
V	Above	9	7.61	3.32	4.80	5.88	6.70	7.53	..
	Below			3.35	4.80	5.88	6.64	7.52	..
VI	Above	7	7.46	3.14	4.63	5.54	6.26	6.77	7.40
	Below			3.21	4.73	5.58	6.19	6.78	7.41

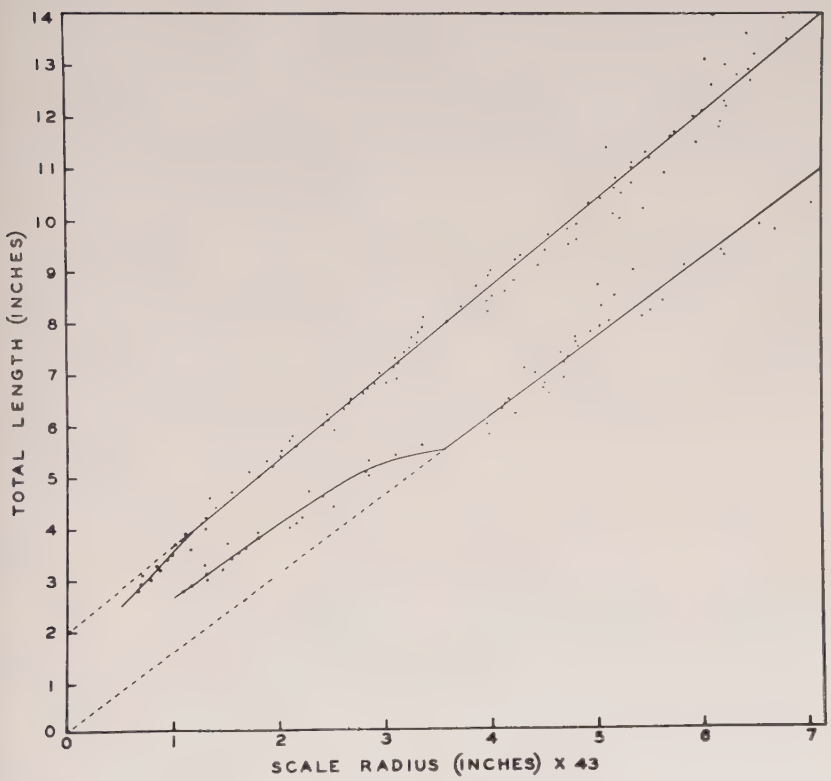

FIGURE 8.—Relation between fish length and the radius of "key" scales above (upper curve) and below the lateral line (lower curve). The dotted portions are extensions of straight lines fitted to data for the larger fish. Dots show the empirical data.

Body-Scale Relation in Three Great Lakes Populations of Yellow Perch

The studies that have been made of the body-scale relation for three Great Lakes populations of yellow perch (Lake Erie, Saginaw Bay, Green Bay; all key scales from the same location below the lateral line) agreed on two points: the body-scale ratio was nearly constant among the larger

fish; shorter lengths computed by direct proportion were underestimates. The populations differed, however, as to the length range over which direct-proportion calculations were inaccurate and as to the size of the correction needed at a particular length (Table 9). Differences between

TABLE 9.—*Corrections to be added to direct-proportion calculated standard lengths of three stocks of yellow perch to bring the values into agreement with the empirically determined body-scale relation in small fish.*

[Body-scale relation based on key scales below the lateral line. Data for Lake Erie adapted from Jobes, 1952; those for Saginaw Bay from Hile and Jobes, 1941.]

Direct-proportion calculated length (millimeters)	Correction to be added			Direct-proportion calculated length (millimeters)	Correction to be added		
	Lake Erie	Saginaw Bay	Green Bay		Lake Erie	Saginaw Bay	Green Bay
36	19	..[1]	..[1]	80-83	6	5	18
37-42	18	16	..[1]	84	5	4	18
43-45	17	15	..[1]	85-86	5	4	17
46-49	17	14	..[1]	87	4	4	17
50-53	16	13	..[1]	88	3	4	16
54-56	15	12	21	89	3	3	16
57-58	14	12	21	90-91	2	3	16
59-60	14	11	21	92	2	2	16
61-63	13	10	21	93	1	2	16
64	13	10	20	94-95	1	2	15
65-67	12	9	20	96-97	..	1	14
68	12	8	20	98-99	..	1	13
69	11	8	20	100-101	..	1	12
70-71	10	8	20	102-104	..	..	11
72	9	8	19	105-106	..	..	9
73-74	9	7	19	107-108	..	..	8
75	8	7	19	109-110	..	..	6
76-77	8	6	19	111-112	..	..	5
78	7	6	19	113-114	..	..	4
79	7	6	18	115-116	..	..	2

[1]Not determined.

the Lake Erie and Saginaw Bay stocks were small. Corrections were needed for direct-proportion calculated lengths of Lake Erie fish up to 96 millimeters standard length[5] and in Saginaw Bay up to 102 millimeters. Differences between corrections at corresponding lengths likewise were small. Largest was at 68 millimeters where the correction to be added was 12 millimeters for Lake Erie and 8 millimeters for Saginaw Bay. At other lengths this difference was 1 to 3 millimeters or nil. The use of the body-scale curve from one of these two stocks for computing growth of the other, though not fully justified, would not lead to serious error.

The comparison of the data for Saginaw Bay and Green Bay reveals an entirely different situation and discloses the reason for the unsatisfactory results when the growth of yellow perch from Green Bay was

[5]Table 9 was prepared in terms of millimeters of standard length because Hile and Jobes (1941) presented their data in that form and Jobes' (1953) corrections in inches had been adapted from a tabulation set up originally in millimeters.

computed from the body-scale curve for Saginaw Bay fish. The direct-proportion calculations required correction over a much greater range of length in Green Bay (up to 117 millimeters) than in Saginaw Bay (to 102 millimeters). Furthermore, the values of the corrections at corresponding lengths were consistently greater for the Green Bay fish — often by a wide margin. Over the length range of 54-108 millimeters (direct-proportion) estimates of length of Green Bay perch made from the Saginaw Bay curve are in error by 8 to 14 millimeters. The errors then decline to nil at 117 millimeters.

Recommendations on Procedure

The data on the body-scale relations based on the same key scale in three stocks of yellow perch and on two different key scales from the same stock lead to two important rules of procedure: collectors of scales should be consistent as to the position on the fish's body from which the scales are removed; computations of past growth from scale measurements should not be attempted until the body-scale relation is known for the stock under study.

Acknowledgments

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The collection of material was facilitated by the cooperation of the commercial fishermen and conservation officers of Michigan and Wisconsin. Particular thanks are due: Joseph DeWitt, Frank Korchak, and Alfred LaVallee of the commercial fishing industry; conservation officer Donald Eurs, and biologist Thomas L. Wirth of the Wisconsin Conservation Department; and Donald Mraz and Alan Bennett of the Sturgeon Bay field station of the Fish and Wildlife Service.

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SOME INTERESTING ASPECTS OF FISHERIES EXPLORATION — 1956

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ABSTRACT

Annual fishery production of the United States must be increased at least 500 million pounds by 1965 to meet demands of population growth. From our knowledge of the commercial fisheries it appears that an additional supply of such magnitude will be found only by pushing our fishery frontiers seaward; by examining the mid-water regions of known fishing areas and by improving fishing gear. In 1956, fisheries exploration has located new deep-water shrimp resources in the Gulf of Mexico and off the South Atlantic coast of the United States. It has also led to charting of productive shrimp grounds in the North Pacific Ocean off the Washington coast. Gaps in the knowledge of the seasonal distribution of yellowfin tuna in the Gulf of Mexico have been closed. With the development of a prototype telemeter for attachment to a mid-water trawl to give continuous depth and temperature information, the potentialities of this fishing gear are improved.

INTRODUCTION

About 70 percent of the United States commercial fisheries catch consists of fish taken from the surface layer of the sea; the upper 100 feet of water. The other 30 percent of the marine catch consists of bottom fish and shellfish taken from grounds lying mostly within the 200 fathom line. This catch, averaging about 4½ billion pounds annually, is harvested from only a minute portion of the vast oceans adjacent to our continent.

Examination of projected annual United States population increment shows that the annual catch must be increased at least 500 million pounds by 1965 to maintain the present proportion of fish in the American diet. Where can we find an additional supply of such magnitude without overtaxing existing fisheries? It appears from our knowledge of the commercial fisheries that the bridging of this 500-million-pound gap by 1965 is most likely to be achieved by pushing our fishery frontiers seaward; by examining the mid-water regions of presently known fishing areas; and by improving gear. Commercial fishermen sense these possibilities and some have taken advantage of them. The U. S. Fish and Wildlife Service is lending encouragement in this respect and is pointing the way to utilization of new marine resources through the operation of a modern fleet of deep-sea exploratory fishing vessels and a specially equipped gear-research vessel. In the course of these activities there have been some commercially promising developments in 1956; some, to a certain degree, unexpected.

Shrimp

This year marked the first consistency in catches of deep-water red shrimp, *Hymenopenaeus robustus,* in the Gulf of Mexico and off the Atlantic coast of Georgia and Florida by Fish and Wildlife Service exploratory vessels. Prior to capture of red shrimp in the Gulf in 1950 during exploration with the vessel *Oregon,* this species was known only through a few museum specimens. The commercially significant catches obtained in 1956 follow a relatively long period of systematic reconnaissance carried out during the preceding five years, chiefly with the *Oregon* in the Gulf, and more recently with the chartered vessels *Pelican* and *Combat* off the coast of the South Atlantic States. Red shrimp seem to be generally distributed in deep-water regions all the way from Cape Cod to Texas, but at the present time three especially productive areas have been located. The first of these is a 200 to 300 fathom strip eastward from the mouth of the Mississippi River to the DeSoto Canyon off Pensacola, Florida; the second is an area in 220 fathoms west-southwest of Dry Tortugas and the third is off the northeast coast of Florida beyond the 100 fathom curve. On a recent cruise of the *Combat,* 4,200 pounds of red shrimp were taken in four days off St. Augustine, Florida; an indication of the potential of those grounds.

A smaller deep-water species of shrimp, *Penaeopsis megalops,* is generally found mixed with most of the red shrimp catches. This species is of average smaller size than the red shrimp and probably is not potentially as important commercially.

Deep-water trawling for shrimp presents many problems. Enough of them have been solved to encourage response by the fishing industry and the first commercial vessel so fishing began utilization of this resource in August 1956. This type of fishing requires a larger winch with a greater wire capacity than is carried on most shrimp vessels today. A sensitive depth recorder with a range to 300 fathoms and a Loran instrument are also important adjuncts. Loran makes possible the accurate determination of the ship's position and exact location of the grounds under all conditions. The most successful exploratory fishing results have been achieved with a 40 foot trawl of the usual shrimp mesh sizes towed on a single wire cable but the use of larger nets is entirely feasible.

A preliminary assessment of the situation shows a correlation of water temperature and red shrimp concentration, which suggests that it may be profitable to equip deep-water fishing vessels with some type of reversing thermometer for quick location of the best fishing grounds. Gear specialists of the Fish and Wildlife Service have developed a simple metering device attached to trawl doors to measure the distance traveled by the net on the bottom. This device determines proper functioning of the trawl when low-

ered in deep-water. Techniques developed for handling the deep-water gear differ appreciably from methods used for shrimp trawling in shallower waters.

Discovery of sizeable concentrations of the ocean shrimp, *Pandalus jordani,* off the coast of Washington in April 1956 by the Service's exploratory fishing vessel *John N. Cobb* has created considerable interest. Although this species is known to fishermen from incidental appearance in their catches, the charting of a productive area almost 100 miles long between the 50 and 100 fathom lines was a significant development. Best experimental production ran as high as 2,000 pounds of shrimp per hour with catches consistently remaining above 500 pounds per hour.

Yellowfin Tuna

Substantial subsurface stocks of yellowfin tuna, *Thunnus albacores,* were first discovered several years ago in the Gulf of Mexico during exploratory fishing by the vessel *Oregon,* but knowledge of seasonal availability of this species in the Gulf has been lacking. In 1956, this gap was closed by obtaining information on the location of yellowfin during the spring months. Exploration in the Gulf of Campeche in the Southwestern part of the Gulf of Mexico during March and April, located sizeable concentrations of yellowfin tuna at the time of year when they are not abundant, or in some cases absent, in other areas in the Gulf of Mexico. Here the *Oregon* took 52,000 pounds of yellowfin on 17 longline sets, averaging 59 baskets of gear with 10 hooks each. Eighty yellowfin, as well as some bluefin tuna and marlin, were tagged for biologists. The yellowfin averaged about 100 pounds each. Previous exploration in the Gulf of Mexico had established the presence of yellowfin tuna in sufficient concentrations for commercial longlining at all seasons except the late winter and early spring months.

It now seems evident that yellowfin tuna are available for commercial longline fishing in the Gulf of Mexico year around. Present knowledge indicates that they occur in the greatest abundance in the Western Gulf and Campeche areas in the later winter and spring months and in the North Central Gulf regions in the summer and fall. Importance of a source of supply not limited seasonally is obvious in the development of a new fishery.

Emphasis has been placed on development of longline fishing methods suitable for Gulf vessels and fishermen. Longline fishing techniques used aboard the *Oregon* are basically those traditionally used by the Japanese but have been somewhat improved and are more costly. However, savings because of reduction of crew made this method commercially feasible in the Gulf. Several vessels have started fishing for tuna in the Gulf of Mexico and some tuna processing began on an experimental scale in 1956 at Gulf ports.

Improvement of Mid-water Fishing Gear

During exploration for stocks of fish of commercial importance in mid-water depths, it soon became obvious that improvements were needed in present one-boat, mid-water trawl designs and that an accurate depth-indicating device was essential. In 1956, specialists at the Service's gear research station at Coral Gables, Florida, undertook underwater observation of mid-water trawls of several designs by use of closed circuit television and skin divers wearing self-contained underwater breathing apparatus. Television instruments and subsurface carrying vehicles for this equipment especially modified at this station for the underwater work have been effective aids in gauging trawl performance.

Improvements were developed in design of trawls and a program started to test mid-water trawls under various conditions. Such tests required a device to measure accurately the depths at which the trawl was fishing. An underwater telemeter for depth and temperature measurement was designed and built by the Marine Laboratory of the University of Miami under contract with the Service. Basically, this prototype instrument is designed for attachment to the trawl and provides directional transmission of impulses to a hydrophone or receiving transducer attached to the vessel below the wake of the propeller. The telemeter serves both as an accurate depth sensing and temperature sensing device, and gives continuous information to a depth of 200 fathoms (Stephens and Shea, 1956).

By use of this instrument along with a recording "Sea Scanar," a sonar type device, on the vessel *John N. Cobb* in the North Pacific during 1956, 20-minute trawl tows took a mixed catch as great as 5,500 pounds. Experiments are also being conducted in the North Atlantic by the vessel *Delaware* to determine the applicability of this gear to fishing for ocean perch, *Sebastes marinus*.

Commercial application of mid-water trawling with the aid of telemeter and sonar instruments is not in immediate sight but progress during the year toward the development of a practical one-boat trawl for commercial fishing in mid-water depths has been notable. Some simplification of the telemeter is desirable for commercial use, and further experiments to make it commercially feasible are planned for the future.

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COUNTING FENCE OF NETTING

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Abstract

A two-way fence of netting is described. It has been used for counting ascending adult salmon *(Salmo salar)* and descending salmon smolts in Newfoundland rivers near the mouth where depths have ranged from 1 to 9 feet. The traps and barriers are constructed in sections which can be easily dismantled and transported to another river. Also sections of netting in the barriers which become clogged with debris during flood conditions can be readily replaced with clean sections.

Introduction

A program of general surveys of salmon *(Salmo salar)* resources on some of Newfoundland's major rivers was initiated in 1951. One river was surveyed each year so as to cover a large number of rivers in a relatively short time. A counting fence (weir and trap) that could be easily installed and readily transported from river to river was needed. Fences of many types and variations have been described by O'Malley (1920); Foerster (1929); Shetter (1938); White (1939); Pritchard (1944); Brett (1948); Hayes (1953); Whalls, Proshek, and Shetter (1955); and Smith and Saunders (1956). In 1946 Brett (1948) used a netting fence and a central trap to capture migrating young sockeye salmon *(Oncorhynchus nerka)* in Lakelse River, British Columbia. Netting appeared to be a more suitable material for temporary fences than pickets, iron rods, or wire cloth.

A short fence of netting was first used in Newfoundland on Black River in 1946 to count salmon entering the river after an opening had been made in a dam which completely barred the river (Figure 1). Since then one-way fences of netting to count ascending salmon have been used on Gander River in 1951 and on Terra Nova River in 1952. A two-way fence of netting to count both ascending salmon and descending smolts was first used on Bay du Nord River in 1953 and on Little Codroy River in 1954. It is the two-way fence that is described in this paper. Its special feature is its suitability for construction of barriers and traps of small units which are easy to install, to replace, or to transport.

The width of Bay du Nord River where the fence was operated was 580 feet. The depth of water at the trap ranged from 1 to 9 feet during the season of 1954. The highest flow during installation of the fence

FIGURE 1.—Map of the southern half of Newfoundland showing locations of counting fences on salmon rivers.

in 1953 was 5,290 cubic feet per second. The highest during the operation of smolt fence was 2,850 cubic feet per second and the highest during the operation of the salmon fence was 2,120 cubic feet per second.

DESCRIPTION OF FENCE

The fence under consideration is roughly X-shaped (Figure 2). It consists of two separate traps, placed side by side in midstream, and four arms. From the upper end of the pair of traps an arm extends upstream to each bank, and from the lower end one extends downstream to each bank. The two upper arms lead smolts moving downstream into one of the traps, and the two lower arms lead adult salmon migrating upstream into the other.

Each arm of the fence consists of sections of netting suspended from a steel cable which is supported by a number of piers. The angle of the arms to the direction of flow is approximately 45°. The actual angles of the four arms of the fence on Bay due Nord River were 45°, 50°, 50°, and 30°. Advantage is taken of projections in the river bank to shorten the arms rather than adhering rigidly to the 45° angle.

TRAPS

The salmon and smolt traps are similar in construction. The outside dimensions of the trap (Figure 3A) are: length 10 feet 3 inches, width

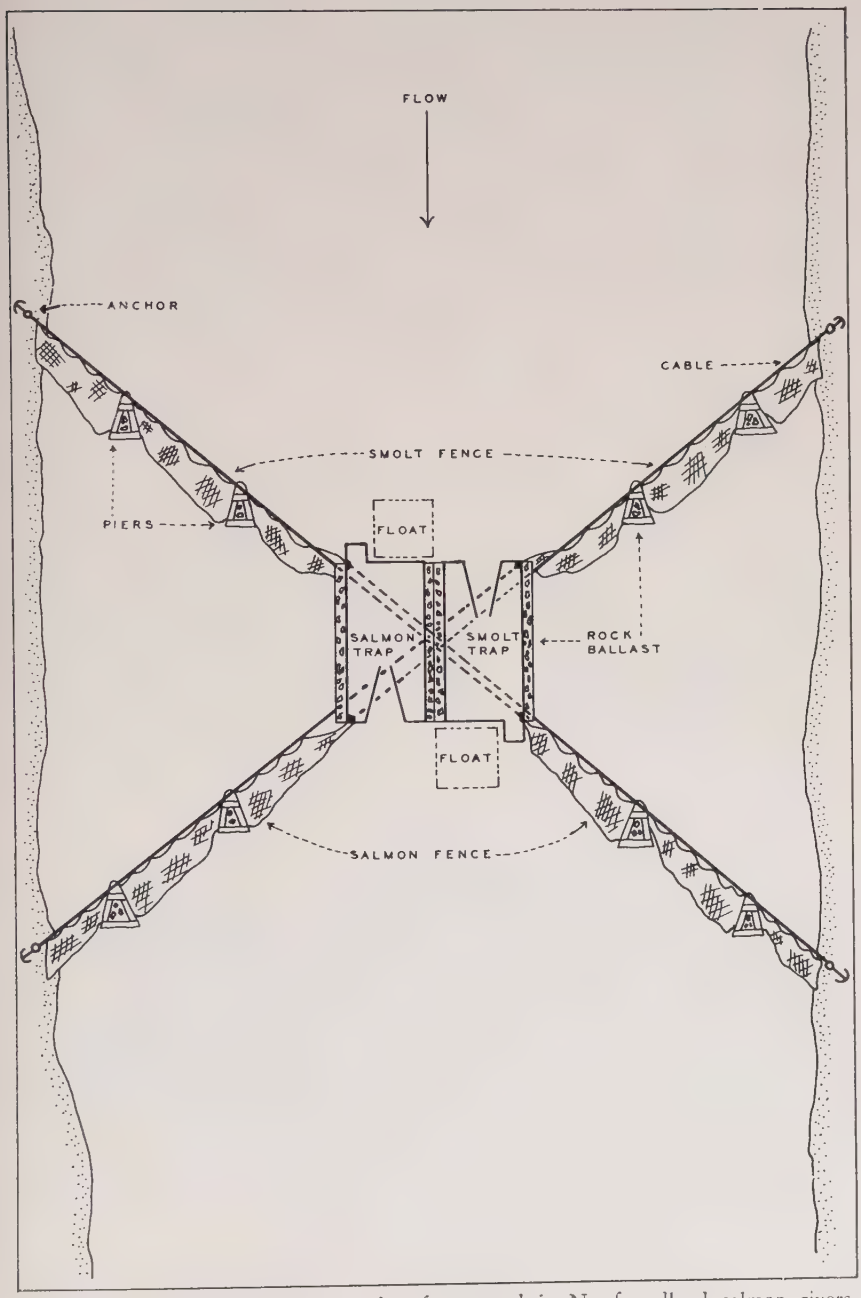

FIGURE 2.—Plan of two-way counting fence used in Newfoundland salmon rivers.

9 feet 3 inches, and height 10 feet 3 inches. It is built in sections using 2- by 4-inch lumber for the framework, and assembled by bolting the sections together with galvanized carriage bolts. A funnel the full height of the trap tapers from 5 feet to 1 foot, and extends into the trap 6 feet. Wire screens are fitted between uprights of the framework to give a flush surface on the inside. This is an improvement over earlier types where screens were fastened to the outside of the framework, thus making the inside surface irregular. The screen frames (4 feet 8½ inches by 3 feet) are made of 1¾- by 1¾-inch lumber, and are covered with 16 gauge, galvanized steel wire cloth. The screens are fastened to the uprights of the trap with sash screws, and are arranged in two tiers all the way around the trap so that at low water the top tier can be removed for greater convenience in working. 1-inch-square mesh is used in the salmon trap screens, ½-inch in the smolt trap screens, and ¼-inch in the trap bottoms.

Ballast pounds on both sides of the trap are supported by projecting floor joists. The pounds extend the full length of the trap, and are 2 feet wide and 4 feet high. The entire side of the pound is hinged at

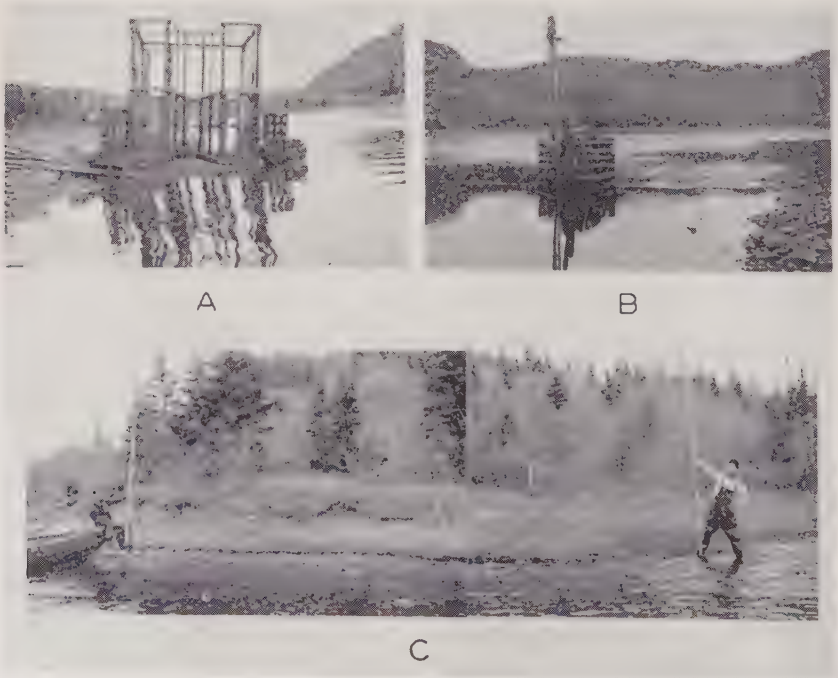

FIGURE 3. A — Trap being launched; B — Part of fence showing pier at low water; C — Net section complete with pole at each end and chain lashed to foot rope.

the top and fastened at the bottom with sliding bolts which have wires attached running to the top of the trap. When the trap is to be removed from the water the pounds can be readily emptied by pulling on the wires. The bottom of the pound slopes away from the trap so there is little difficulty in getting all the rocks to slide out into the river.

Fish are removed from the trap by way of an elevator pound which is situated at the upstream end of the salmon trap and at the downstream end of the smolt trap. The pound is 9 feet 11 inches high, 3 feet 10 inches long, and 3 feet wide. Between the pound and the trap is a vertically sliding gate. An elevator of angle iron frame with a bottom of fine mesh netting is fitted into the pound so that fish cannot escape but yet is free to move up and down. It is raised by means of a 4-inch block and tackle, and lowered by the weight of the iron frame when released.

Piers

These are crib structures filled with rock (Figure 3B). Triangular in shape, they have equal sides 6 feet long and various heights depending on the depth of water. It is not necessary to have them the full height of the water. For example, on Bay du Nord River piers 6 feet high were quite satisfactory in 9 feet of water. The bottom of the pier is made of sticks, around 3 inches in diameter, spiked to two logs which are approximately 8 inches in diameter. The logs in the walls average around 5 inches in diameter. The upstream corner is covered with 1-inch boards to prevent the netting from catching up on the ends of the logs. The upright pole at the upstream end, which supports the suspension cable, is from 6 to 8 inches in diameter, and its height depends on the depth of the water.

Suspension Cable and Anchorage

The type of cable was recommended by Canada Wire and Cable Company Ltd. It is referred to as 6 by 7 galvanized plow steel wire rope with fiber center. This means that it is made up of six strands around a fiber core with seven wires in a strand. It is well qualified to withstand abrasion, but it is not so flexible as types with a greater number of wires. The size of wire used is 7/16 inches in diameter which has a breaking strength of 8.5 short tons.

Anchorage is provided by embedding an 80-pound anchor in the bank and cross spiking with stakes to prevent slipping. A large, solid tree is also used if one is available in the spot where it is needed. Trees have been used as often as anchors.

Net Sections

All the sections (Figure 3C) are 40 feet long but vary in depth from 15 to 20 feet for the smolt fence and from 12 to 18 feet for the salmon fence. The smolt sections are made of 9-thread tarred cotton

twine, 1-inch stretched mesh, and the salmon sections of 12-thread tarred cotton, 2-inch stretched mesh. Head and foot ropes are 6-thread Manila rope. The twine has as little gathering as possible because the more open the meshes, the greater the amount of dirt which can pass through.

The nets as they came from the factory are prepared on the job by attaching a small pole to each end of the net and ½- to ¾-inch chain to the foot rope. Floats are not needed because the head rope is fastened to the suspension cable. Marline is used to lash the poles and chain to the net. The foot rope is fastened a few inches from the bottom end of the pole so that the foot rope will rest on the bottom when the pole is driven into the bottom. When the skirt line is lashed to the pole, any surplus netting is gathered near the bottom. This slack netting at the bottom helps to keep the foot rope on the bottom.

Chain is very satisfactory for sinkers because it keeps the whole foot rope tight to the bottom and does not get tangled in the netting when being handled. Any old chain is suitable provided it is the right size. Chain less than one-half inch is not heavy enough and over three-quarter inch, although excellent for retaining nets on bottom, is rather heavy for pulling into small boats.

The rule followed in determining the depth of net sections is to double the known or expected depth of water where they will be used. This provides sufficient bag so there is not too much strain on the twine and the foot rope does not lift.

Installation

The trap is assembled on the bank of the river upstream from the location chosen for the fence. Three logs are bolted to the floor of the trap so that it will not be damaged when it is being pushed into the river on skid logs. Empty oil drums lashed to the sides of the trap keep it afloat while it is being towed to the required position with two 14-foot, outboard boats. The trap is temporarily held in position by means of two anchors which are sometimes left all season as an additional aid in holding the trap in place. When the drums are removed, rock from the two boats is simultaneously dumped into the ballast pounds on the sides of the trap until it rests securely on the bottom. A second trap is similarly placed in the river beside the first.

To indicate positions for piers, markers are tied every 35 feet on a small rope stretched from the trap to the anchor on the river bank. The piers, which are built on the river bank, are floated into position in the same manner as described for the traps. A large pole is driven into the bottom at the upstream end of each pier and spiked to it. A platform is built on one of the boats so that a man can stand on it to drive the poles with a large maul. A hardwood bracket for supporting the cable is nailed to each pole so that it is level with the top of the trap. The cable which has two 12-inch turnbuckles at each end is fastened

to the distant corner post of the trap, placed in the brackets, and held taut at the shore end with block and tackle while it is being secured to the anchor with turnbuckles and anchor shackle. When the cables on the four arms have been installed, they are tightened by means of the turnbuckles just enough to take out the sag.

The 40-foot net sections are next placed between the piers. One end pole is driven into the bottom and tied to the pier pole. The boat is pulled towards the next pier and the headrope of the net is tied to the cable at intervals of 2 to 3 feet. Nets are set with the current, and three men are usually required. Four, however, make an ideal crew especially during periods of high water when two boats are often needed. At such times the current is so strong difficulty is experienced in keeping the second net pole in place while it is being tied to the pier pole. The operation is quite simple if two additional men are available to pull on a rope attached to the end of the net from a second boat moored a few feet away from the pier.

Operation

Fish Handling

Two floats are used, one at the downstream end of the traps for handling smolts and one at the upstream end for salmon. The float consists of a wood floor, 8 feet by 10 feet, resting on four empty oil drums, with a framework of small poles covered on top with a tarpaulin or tent fly for protection from sun and rain. A work table is placed in the center of the float and an anaesthetizing tank on the side next to the elevator. The tank is 3 feet square, 2½ feet deep, made of waterproof canvas, and suspended from poles to keep the sides upright. A recovery cage (8 by 3 by 3 feet) placed in the river beside the float has a wood frame covered with wire cloth.

In counting and marking operations a number of smolts are driven into the elevator pound, the door is closed, and the elevator is raised to the surface. They are dipped from here into the anaesthetizing tank using a small dip net made of cloth on a wire frame padded to prevent injury. One at a time the anaesthetized smolts are transferred to the table for tagging, fin-clipping, and measuring, and then released into the recovery cage. When all the smolts in the trap have been handled in this way, the recovery cage is tipped on its side and the smolts are free to continue downstream. In salmon clearing operations only one or two at a time are allowed to enter the elevator pound. The salmon elevator is fitted with a false bottom, and when the elevator is raised to the surface, this false bottom is tilted so that the salmon rolls into the anaesthetizing tank.

The anaesthetic is urethane, ethyl carbamate, which is used at the rate of 1 pound to 20 imperial gallons of water. Both water and urethane are added as required and the whole mixture renewed occasionally. Five to

six pounds of urethane per year were used on Bay du Nord River.

Care of Nets

The nets are inspected for breaks in the twine and cleaned at least once a day. Logs and branches are removed by hand, but a large dip net has been found to be very effective for removing small fragments such as leaves and grass. The iron hoop of the dip net is covered with canvas so as not to damage the netting. If a section of net becomes very dirty, which often happens during flood conditions, it is removed and a clean section put in its place. Most of the sections have to be changed several times a month to make minor repairs. At least once a month all sections are changed, washed, and dried to prolong the life of the netting. In changing sections the new section is always placed in position on the upstream side of the fence before removing the old section from the downstream side.

Tarred cotton netting is very satisfactory. The same netting has been used for two seasons on Bay du Nord River where the length of ths smolt season is 2½ months and the salmon season 5 months. At the end of the season the netting is tarred in a mixture of 3 imperial gallons of pine tar and 20 gallons of kerosene. The mixture is boiled until all the tar is completely dissolved. Almost continuous stirring is necessary as the oil is brought to a boil. The boiled mixture is poured into a tank and the netting dipped in it. The netting is then put on poles over another tank to drain for a few hours and afterwards spread to dry. The recovered mixture can be used again. All netting should be well dried before storing for the winter.

River Traffic

On Gander and Bay du Nord Rivers it was necessary to provide a passage in the fence for canoes and small boats. This was done by lowering the head rope of one section to the surface of the water and attaching a small pole to each side of it. This kept the head rope on the surface and also prevented damage to the net by boats when passing over it. When salmon were running, the head rope was raised out of the water at night because boats were not on the move after dark.

During the 1954 season 550 saw logs were passed over the lowered section of the fence on Bay du Nord River without any difficulty. The logs were held in a boom a short distance above the fence and around 25 at a time were hitched together in a raft and towed by motor boat to the lowered section of the fence which was depressed a few inches below the surface while the boat and raft of logs drifted past.

Acknowledgments

Many of the salmon personnel in Newfoundland have contributed to the design and methods of installation and operation of this counting fence. Fred A. Day,

who was in charge of fence operations, and Alex P. Cowan, who relieved him at times, were also most helpful in preparation of the paper. Temporary assistants in the field had experience in commercial fishing and their knowledge of nets was invaluable.

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EFFECT OF FOREST SPRAYING WITH DDT ON AQUATIC INSECTS OF SALMON STREAMS

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Abstract

Number and volume of aquatic insects emerging from tributaries of the Miramichi River of northern New Brunswick, where forest-covered watersheds had been sprayed from the air with 0.5 pounds of DDT per acre, are compared with insect emergence from unsprayed streams. Adult insects were captured as they emerged from the water in yard-square cage-traps. In the streams affected by DDT fewer kinds of insects, particularly of the larger species such as caddisflies, were found. The sprayed streams had, generally, larger numbers than the unsprayed but in all sprayed streams the volume represented was significantly lower because of the relative scarcity of the larger forms. The insect fauna of the sprayed streams was found to be deficient in the kinds of insects on which the salmon were mainly feeding in the unsprayed streams.

Early in the summer of 1954, an extensive forest area in the northern part of the province of New Brunswick was sprayed to control a serious outbreak of the spruce budworm, *Choristoneura fumiferana* (Clem.). In 1956, as the epidemic spread, other areas in the same general region were sprayed. DDT in oil was applied from aircraft at the rate of 0.5 pounds of DDT per acre.

As a result of the spraying in 1954, many young Atlantic salmon, *Salmo salar* L., were killed in the Miramichi River system, one of the better salmon streams of the Maritime Provinces. An examination was made of the bottom fauna about a month after the spraying and in the most affected parts no aquatic insects were observed. Sections of the same river outside the spray area were found at this time to have an abundant and varied fauna. During the spraying, collections were made of many individuals of the larger and more conspicuous species of aquatic insects that were found dead. These are species which, if their life cycles had not been interrupted, should have been in evidence when the streams were examined later in the summer. They were found in the unsprayed parts of the river at this time.

Therefore, as part of their programme of research on the Atlantic salmon, the Fisheries Research Board of Canada decided to investigate the effect of the spraying on the aquatic insects. The Northwest Miramichi River was selected as the locus of the work with headquarters in a small field laboratory at Curventon, Northumberland County. The condition of the fauna has been followed through the summers of 1955 and 1956. In the former the field work and preliminary analysis of data

was carried out by D. A. Hurley and in the latter by J. Malia, student assistants. Dr. J. L. Hart, director of the Biological Station at St. Andrews, N.B., Dr. C. J. Kerswill, in charge of Atlantic salmon investigations and other members of the staff of the station provided facilities and gave general supervision.

Use and Location of Insect Cage-Traps

For the 1955 programme four tributaries of the Northwest Miramichi River were selected. Two of these, the North Branch of the Big Sevogle and one of its small tributaries, were examined at points more than five miles within the spray boundary. The other two, Millstream Brook and Trout Brook, were more than five miles outside the spray boundary. This arrangement minimized the possibility of contamination of the controls by spray and also mitigated against the re-establishment of insects in the sprayed streams by immigration from unsprayed ones. The emerging insects were sampled by means of cage-traps, two of which were placed adjacently in rapids at each location. Those in the North Branch of the Big Sevogle and those in the Millstream Brook were placed approximately fifteen miles downstream from their sources. The cage-traps were placed in Trout Brook and the small tributary of the Sevogle River at approximately nine miles and one mile respectively from their sources. The Millstream Brook and the Big Sevogle River were similar in size, rate of flow, type of bottom and in thermal conditions at the study stations. The other two streams were smaller and colder, the small tributary of the Sevogle River being the coldest. The 1955 collections gave a basis for comparing the insect populations of streams a year after they had been sprayed with DDT with the insect populations in the two control streams which had not been sprayed at any time.

In 1956 the watershed of the North Branch of the Big Sevogle River was not sprayed, thus affording an opportunity to study the fauna of aquatic insects in the second year following spraying. Trout Brook was sprayed for the first time in that year and this gave an opportunity to evaluate the effect of the spray on the insects in the year of spraying. The Millstream Brook was not sprayed in 1956 and so remained as a control. The locations of the cage-traps in the Big Sevogle River, Trout Brook and Millstream Brook were approximately the same in 1956 as in 1955 but the small tributary of the Big Sevogle was not examined in 1956. Three cage-traps were placed in each of the three continuing stations in 1956 instead of two as in 1955.

The cage-traps are a yard square and are designed to catch and retain the insects which emerge from the surface of the water of the rapids (Ide, 1940). In order to insure that the traps would retain the smaller insects three sides and the top were covered with a glazed wire screening, "windowlite," and the fourth side with 25 mesh copper screening rather than being entirely of 15 mesh as specified in the original description. The

cage-traps were emptied at approximately 24-hour intervals and the collections analyzed for the kinds, numbers and total volumes of insects. The collections began in the first week of June and ran until the first week of September. During this period collections were made on five days of each week in 1956 with the exception of one daily collection for eight cages and two daily collections for one cage which were missed. In 1955 several daily collections were missed from all cages owing to freshets, particularly in the early summer. The fact that six daily collections were generally taken each week compensated for these losses.

The emergence of insects into the cages at the different stations was compared on a sixty day basis although the number of daily collections from different cage-traps varied from 58 to 70 for the season.

Insect Emergence from Sprayed and Unsprayed Streams

The results will be presented under three headings:

(1) Effect of the spray on the aquatic insects in the year of spraying; (2) effect of the spray on the aquatic insects in the year following spraying and (3) effect of the spray on the aquatic insects in the second year following spraying.

Emergence of Aquatic Insects in the Year of Spraying

Trout Brook was the only stream of the sample series which was sprayed in 1956, the same year in which its insect fauna was studied. Figure 1 shows the change in the average number and corresponding volume of insects emerging daily into the three cage-traps used in sampling at this station. The spray was applied June 14 to 17. Before this period the number of insects emerging was not large but the corresponding volume was relatively high. In the three weeks following the spraying the emergence of insects was almost negligible. From the middle of July to the middle of August there was, however, a great increase in the number of insects emerging but it is evident from a comparison of the peak of the number curve (B) with the corresponding peak of the volume curve (A) that most of the insects were small. There were large numbers of minute chironomids which have little bulk. The sharp rise in the curve of volume at this time can be attributed mostly to caddisflies, larger insects, which emerged during the second and third weeks of July and may have been in the pre-pupal or pupal stage when the spraying was done. In Figure 2 are the corresponding volume (A) and number (B) curves of emerging insects taken from Trout Brook in 1955, the year before it was sprayed. The ratio of volume to number illustrated by these two latter curves and in comparison with the curves of Figure 1 indicates that the insects emerging were fewer but on the average of larger size in 1955 than in 1956. Table 1 gives a further comparison of kinds and quantity of insects emerging at this station in the two years. In Table 1 the emergence of insects

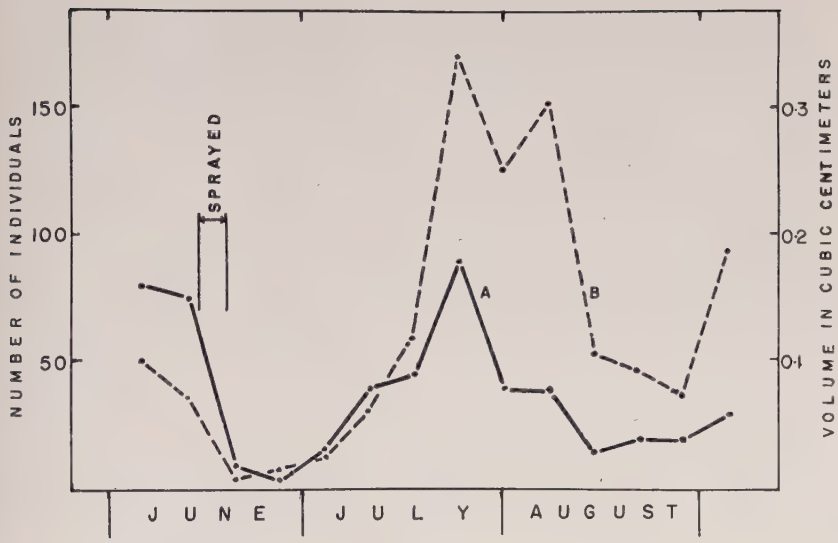

FIGURE 1. Weekly change in number (B) and volume (A) of insects emerging daily into three yard-square cage-traps in Trout Brook in 1956, the year in which the stream was sprayed. Each weekly point is the average of five square-yard 24-hour collections.

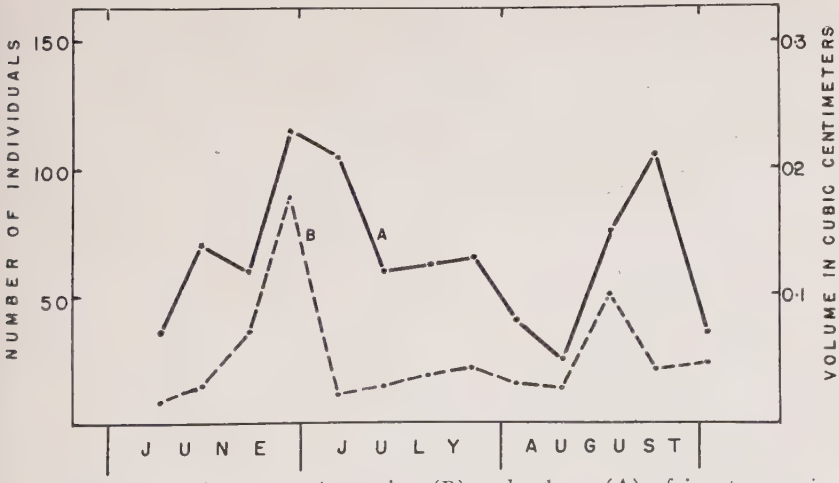

FIGURE 2. Weekly change in number (B) and volume (A) of insects emerging daily into two yard-square cage-traps in Trout Brook in 1955, the year before any spraying had been done in the area. Each weekly point is the average of from four to six square-yard 24-hour collections.

after June 15 in both years is compared on a 60-day basis. Although the number emerging in each cage in 1955 was lower than in 1956 the corresponding volumes were higher in the former year and the insects were of larger size on the average as shown by the ratio of volume to corresponding total number in the last column.

Emergence of Aquatic Insects in the Year Following Spraying

The programme of 1955 was designed to find out the effect of spray on the insects in the North Branch of the Big Sevogle River and its small tributary both of which were sprayed in 1954. The results have been reported on earlier (Kerswill 1956, Hurley 1956). The cages in the Big Sevogle produced less than half the bulk of insects produced by the cages in the Millstream Brook control stream. The insects in the former were small species giving an average size of about one half that of the control. The relatively large number of chironomids was instrumental in determining this size relation. The small tributary of the Sevogle which was also sprayed was not as drastically affected as was the main river. Three species of caddisflies were represented in the collections from its cages as compared to none in those of the Big Sevogle. In both, however, there were significant qualitative differences between the faunas of the sprayed streams and their corresponding controls as shown in Table 3.

Table 1. *Numbers and volume of insects emerging into yard-square cage-traps in Trout Brook from June 15 to September in 1956 and 1955. Trout Brook was sprayed for the first time June 14 to June 17, 1956. All figures are for 60 days.*

Year of Sampling	Cage-trap number	Percentage Number						Total Number	Volume in cubic centimeters	Volume in cubic centimeters / Total number
		Plecoptera	Ephemeroptera	Trichoptera	Diptera					
					Simuliidae	Chironomidae	Miscellaneous			
1955	TV	5.6	11.9	10.6	2.7	66.4	2.8	1493	5.1	0.0034
	TVI	3.3	23.4	15.5	3.9	51.6	2.3	1604	8.2	0.0051
1956	TI	0.9	1.3	3.4	0.1	89.6	4.7	3638	4.1	0.0011
	TII	0.5	0.7	1.4	0.0	95.0	2.5	3973	3.2	0.0008
	TIII	0.6	1.2	2.1	0.2	95.7	0.2	4337	3.5	0.0008

Emergence of Insects in the Second Year after Spraying

In 1956, the second year after the Sevogle area had been sprayed, daily samples of aquatic insects were again collected from the stations in the North Branch of the Big Sevogle. These were compared with those from Millstream Brook which served again as a control. Table 2 shows this comparison. For 1956 the volumes of aquatic insects taken by all cages of the Sevogle series were less than those of the control cages in Millstream Brook although the two highest numbers of insects per cage were taken by two of the Sevogle cages. The ratio of volume to total number in each cage-trap also shows that fewer individuals of species of larger size were represented at the Sevogle than at the Millstream. The percentage representation of the different groups of insects as shown in Table 2 throws further light on this relationship. All but about one thousand of the insects from trap SIII in the Sevogle River were chironomids. The chironomids taken in the survey were mostly minute species of the subfamily Orthocladiinae, in general under three millimeters in length. It was estimated that the 13.5 thousand chironomids taken in this trap gave the same bulk as the remaining thousand which were mainly Ephemeroptera and Plecoptera, all of moderate size. Large Plecoptera were taken only in the Millstream Brook. Some of these were as much as an inch and a half in length and contributed greatly to the bulk of insects taken in samples there. The Trichoptera were in insignificant numbers at the Sevogle, although they formed a significant component of the fauna of the Millstream. Two caddisflies of a species characteristic of slowly flowing water and five microcaddisflies were the only caddis to emerge from the 27 square feet of rapids in the Sevogle covered by the cage-traps during the 70 days of sampling in 1956. None was taken from the 18 square feet of the same rapid sampled in 1955. In contrast 143, 172 and 146 were taken in the three cage-traps of the Millstream Brook series in 1956. Since several species of Trichoptera which had been killed by the spraying of that year were found at the Sevogle station in 1954, it is concluded that this group of insects was almost eliminated from this section of the stream by the spray and in the second year following spraying had not reappeared to any appreciable extent. This decrease in numbers of Trichoptera, which are mainly predatory, may account for the increased abundance of small insects, mainly chironomids, on which they ordinarily feed.

Effect of DDT on Stream Invertebrates

The effect of DDT on invertebrates of streams has been investigated mainly in relation to three operations: (1) forest pest control (2) experimental treatment to evaluate the effect on fish and their food and (3) black fly control. The present investigation fits into the first category. One method of applying the DDT in these three operations has been to spray from aircraft with a solution of the insecticide in oil. Results ob-

tained by this method are of most interest in the present discussion. Results obtained by other methods are also relevant when these methods give concentrations of the poison in the water comparable to those obtained by aerial spraying.

The development of methods for applying the insecticide has led gradually to the adoption of fairly standard procedures. Pertinent literature includes Hoffman and Merkel (1948), Hoffman and Surber (1949), Hoffman and Linduska (1949), Brown (1951), Kerswill (1956) and Hurley (1956) dealing more particularly with forest operations, Hoffman and Surber (1945), and Savage (1949) dealing with experimental applications to streams and Arnason *et al* (1949), Brown (1951) and Jamnback and Collins (1955), on black fly control. In addition, testing of the toxicity of DDT formulations to various forms of stream life has been carried out in the laboratory as is reported by Eide *et al.* (1945), Gjulin *et al.* (1949) and Savage (1949).

Aerial spraying of approximately one pound of DDT per acre has been adopted as a satisfactory dosage for control of many forest pests but a dosage of 0.1 pound per acre or less has been adopted for black fly control.

TABLE 2. *Number and volume of insects emerging into yard-square cage-traps in the North Branch of the Big Sevogle River (SIII-SV) and into cage-traps in the Millstream Brook (MI-III) from early June to early September in 1956. All figures are for 60 days.*

	Year of Sampling	Cage-trap number	Percentage Numbers						Total number	Volume in cubic centimeters	Volume in cubic centimeters / Total number
			Plecoptera	Ephemeroptera	Trichoptera	Diptera					
						Simuliidae	Chironomidae	Miscellaneous			
Sevogle River Sprayed in 1954	1956	SIII	1.5	4.1	0.0	0.8	93.5	0.1	14505	8.4	0.0006
		SIV	1.9	8.0	0.0	1.9	87.5	0.7	7330	6.3	0.0009
		SV	1.7	13.9	0.0	3.4	75.4	5.6	4422	5.5	0.0012
Millstream Brook Unsprayed	1956	MI	8.6	9.6	4.2	0.3	74.8	2.5	3418	11.2	0.0033
		MII	12.6	11.4	4.9	1.1	67.2	2.8	3526	11.2	0.0032
		MIII	7.7	8.9	3.0	0.8	77.7	1.9	4874	13.6	0.0028

TABLE 3. *Approximate number*[1] *of species in the orders Plecoptera Ephemeroptera and Trichoptera which were identified in collections of 1955 from one cage-trap at each location in four streams.*

Order	Category (Genus, Family or Sub-family)	Approximate Number of Species			
		Sprayed Streams		Control Streams	
		SI	SIV	TVI	MVII
Plecoptera (Stoneflies)	Acroneuria	0	0	1	2
	Isogenus	0	1	0	1
	Isoperla	1	1	1	1
	Alloperla	2	2	2	1
	Leuctra	2	2	2	1
	Nemoura	1	1	1	1
	Total	6	7	7	7
Ephemeroptera (Mayflies)	Ephemerella	3	4	5	5
	Paraleptophlebia	1	1	2	2
	Baetis	0	1	4	5
	Pseudocloeon	0	1	2	2
	Heptagenia	0	1	1	1
	Iron	1	2	2	1
	Rhithrogena	0	0	1	0
	Total	5	10	17	16
Trichoptera (Caddisflies)	Rhyacophilidae	1	0	7	6
	Philopotamidae	1	0	1	1
	Psychomyidae	0	0	1	1
	Hydropsychidae	1	0	3	3
	Hydroptilidae	0	0	1	0
	Leptoceridae	0	0	1	1
	Lepidostomatidae	0	0	2	1
	Helicopsychidae	0	0	1	1
	Brachycentridae	0	0	0	1
	Limnephilidae	0	0	1	1
	Total	3	0	18	16
	Grand Total	14	17	42	39

[1]Most species were distinguished but some closely related ones were identified to species group only. This was more frequently done for the more complex faunas of the controls so that the numbers for these are probably disproportionately low.

The former concentration gives good control of many forest pests and it is claimed that it does little lasting damage to other elements of the fauna of the forest (Hoffman and Linduska, 1949). The latter dosage gives good control of the susceptible larvae of the black flies without seriously affecting the other stream arthropods (Jamnback and Collins, 1955). For both operations evidence has been advanced which indicates that dosages lighter than standard were ineffective in bringing about control of the pest and that dosages heavier than standard resulted in elimination of some important components of the fauna.

It follows therefore, that, because of the heavier dosages employed in forest spraying, this operation rather than black fly control measures presents the greatest danger to the life in streams. The dosage reaching a stream in a forest spraying operation would be considered a serious overdosing in a black fly control operation.

In the forest spraying of a watershed there is danger under certain weather conditions that heavy concentrations of the insecticide may reach the streams in runoff. This danger is not present in black fly control operations where only the stream is sprayed.

In the New Brunswick forest spraying already considered, the dosage has been 0.5 pounds of DDT per acre, half the "optimal" amount as referred to above. Nevertheless the resulting differences between the fauna of aquatic insects in sprayed and unsprayed streams was pronounced. The conclusion that these differences are a result of the DDT is supported by similar results reported in the literature. It has been shown by the experiments of several workers including Eide *et al.* (1945), Gjulin *et al.* (1949) and Savage (1949) that concentrations of DDT which result from such sprayings are highly toxic to many kinds of aquatic insects and other organisms. Savage (1949) found that the insect mortality was caused by the DDT and not the oil solvent. The data presented show marked difference between the pre- and post-spray fauna of Trout Brook (Figures 1 and 2 and Table 1) and the fauna of the North Branch of the Big Sevogle River the year following spraying and the fauna of Millstream Brook, a control stream of similar character. In the second year after spraying even more pronounced differences between the fauna of these latter two streams were found, as illustrated in Table 2, and the big differences were in the quantity of insects that emerged, especially when bulk, rather than number, is the criterion of quantity. Pronounced qualitative differences in the fauna of the sprayed and unsprayed streams were also found and are illustrated in Table 3. The small number of species surviving in the sprayed streams contrasts with the larger number in the unsprayed. Some of the species which were absent from the North Branch of the Big Sevogle River and present in the Millstream Brook in 1955 were collected dead from the former at the time of spraying in 1954 which is strong evidence that they were eliminated by the spraying.

In 1956, the second year after spraying, the fauna at the Sevogle Station was little changed qualitatively from 1955 but the proportional representation of the insect groups had altered. The total number of individuals emerging at this location was also greater in 1956 than in 1955. The number emerging into two of these cages in 1956 was greater than the emergence into any of the Millstream Brook controls. However, despite the large numbers, smaller volumes, ranging from a little less than one-half to slightly more than two-thirds those of the corresponding controls, were taken in 1956 as shown in Table 2. Similarly the population of the Trout Brook was numerically higher but volumetrically lower

in 1956, the year of spraying, than in 1955 as Table 1 shows. From the above it seems evident that the spraying had been selective in its action, eliminating many species, but that there were many species which survived. Of those which survived, the small species, particularly chironomids increased prodigiously and were present in greater numbers even in the year of spraying than in normal years. This increase is attributed to short life cycles and fewer predators and competitors. The sprayed streams were low in production of bulk of insects as compared with their controls in all years following spraying in spite of larger numbers of insects emerging in most of their cage-traps.

The population which developed after spraying was qualitatively different from the pre-spray population. Small chironomids were disproportionately abundant and larger forms scarce. The bulk of insects remained relatively low in the sprayed streams and this observation finds little confirmation in the papers cited. Possibly this is because of difference in sampling methods used. The usual apparatus for sampling bottom fauna of rapids is the Surber sampler (Surber, 1937) or modifications of it, the best known of which is that described by Hess (1941). Both are square-foot samplers operated so as to collect aquatic invertebrates from the enclosed area of bottom. The resulting catch gives a measure of the "standing bottom crop" and may be expressed as number or volume or weight of organisms. Such a sampler is particularly suitable for obtaining the total volume or weight since loss of some small individuals, which is inevitable, does not introduce a large percentage error in the result. The sampler is adequate when used, as it was by Surber, to measure the quantity of fish food organisms on the bottom. When, however, the sample is to be expressed as number of individuals, a serious error may result and this error increases with increase in numbers of small animals in the population. In using this sampling technique or others which involve picking over the bottom the author has found that the larger invertebrates are taken but that small species or the young of larger species are poorly represented in the sample. This happens even when it is known from subsequent collections made of emerging adults that larvae were numerous at the time the bottom sample was taken, Ide (1940).

The cage-trap method has drawbacks but would seem to be particularly efficient for taking adults of the small insects, including chironomids, black flies and empids, which are proportional to and more nearly representative of the population on the bottom than are samples taken by other methods. The cage-traps cover a large area and thus a large sample of all emerging insects is obtained. It is not feasible, however, to operate many such traps and therefore the method does not lend itself to extended sampling of surveys. As a research technique it may however provide information which would be of value in interpreting samples taken by other means.

The large number of chironomids and the almost complete absence of

caddisflies are the most conspicuous features of the sprayed streams examined in the present investigation. Davies (1950) has reported on a phenomenal increase in black flies in a stream in the years following DDT treatment. The stream had been sprayed in 1944 from a helicopter with DDT at a rate of six pounds of DDT per acre. Using cage-traps Davies had sampled the populations of emerging black flies from 1939 to 1947. Although almost no black flies emerged in the year that the stream was sprayed the emergence increased in the years thereafter until over 80,000 emerged from a square yard during the summer of 1947 which was about seventeen times the average emergence of the five pre-spray years. These small flies were the dominant group in this stream after spraying.

Th more serious effects of spraying on the fauna from the standpoint of the fish would appear to be the reduction in bulk of fish food and the high proportion of this lessened bulk which is made up of insects which are so small as to be unsatisfactory for the larger young salmon. As much as half the volume of the aquatic insect food of the sprayed streams has been estimated to be these minute insects, leaving only a small quantity of insects which may be more readily utilized. Qualitative changes in the insect populations are significant as it has been shown by Allen (1941) and the present author (1942) that the salmon and trout which are characteristically insectivorous in their younger stages utilize some kinds of insects more than others, depending on availability. Caddisflies are very frequent in the stomach contents of both salmon and trout.

Another and perhaps the most serious consequence of the spraying is that many of the insects which were eliminated have not become re-established even in the second year after spraying. Many of these aquatic insects do not disperse widely and consequently it may be many years before they will be rehabilitated by natural means. In the meantime the fish feed on other organisms, not normally utilized, which persist in the stream after spraying. Hurley (1956) found, for instance, that the salmon fingerlings in the dirth of aquatic insects of suitable kinds fed largely on snails.

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USE OF AN ARTIFICIAL SPAWNING CHANNEL BY SALMON

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Abstract

Investigation of effect of a proposed hydro-electric development on the salmon spawning grounds in Jones Creek, British Columbia in 1949 indicated spawning areas would be so affected that only a small portion of existing runs could be maintained. Methods for preserving the run were suggested and one selected that involved the construction of an artificial spawning channel capable of supporting the existing runs with provision for controlling the flow in the channel and by-passing surplus flows.

Behavior studies of pink salmon *(Oncorhynchus gorbuscha)* and chum salmon *(O. keta)* spawning in the channel were made in 1955 and the survival from egg to fry was determined in 1956 when there was survival of 37 percent of the 428,000 pink salmon eggs calculated to have been available for deposition and 30 percent of the 251,000 chum salmon eggs calculated to have been available for deposition.

In the spring of 1949 the B. C. Electric Co. Ltd. announced a proposal for developing the power potential of the Jones Lake system which is located 100 miles northeast of Vancouver. This involved the construction of a 55-feet-high dam, three-quarters of a mile below Jones Lake, creating a storage reservoir of 72,000 acre-feet capacity. From the western side of the lake a two mile tunnel would be driven to the western slope of the Cheam mountains. From the tunnel the water would be conveyed through 6,000 feet of pressure pipe to a powerhouse on the Fraser River seven miles west of the present mouth of Jones Creek. The available head would be approximately 2,000 feet and at 75 percent efficiency 37,000 continuous horsepower would be available. The details of the project are illustrated in Figure 1.

This anouncement aroused the immediate concern of the Department of Fisheries because Jones Creek was a consistent producer of Pacific salmon, particularly pink salmon *(Oncorhynchus gorbuscha)* during the

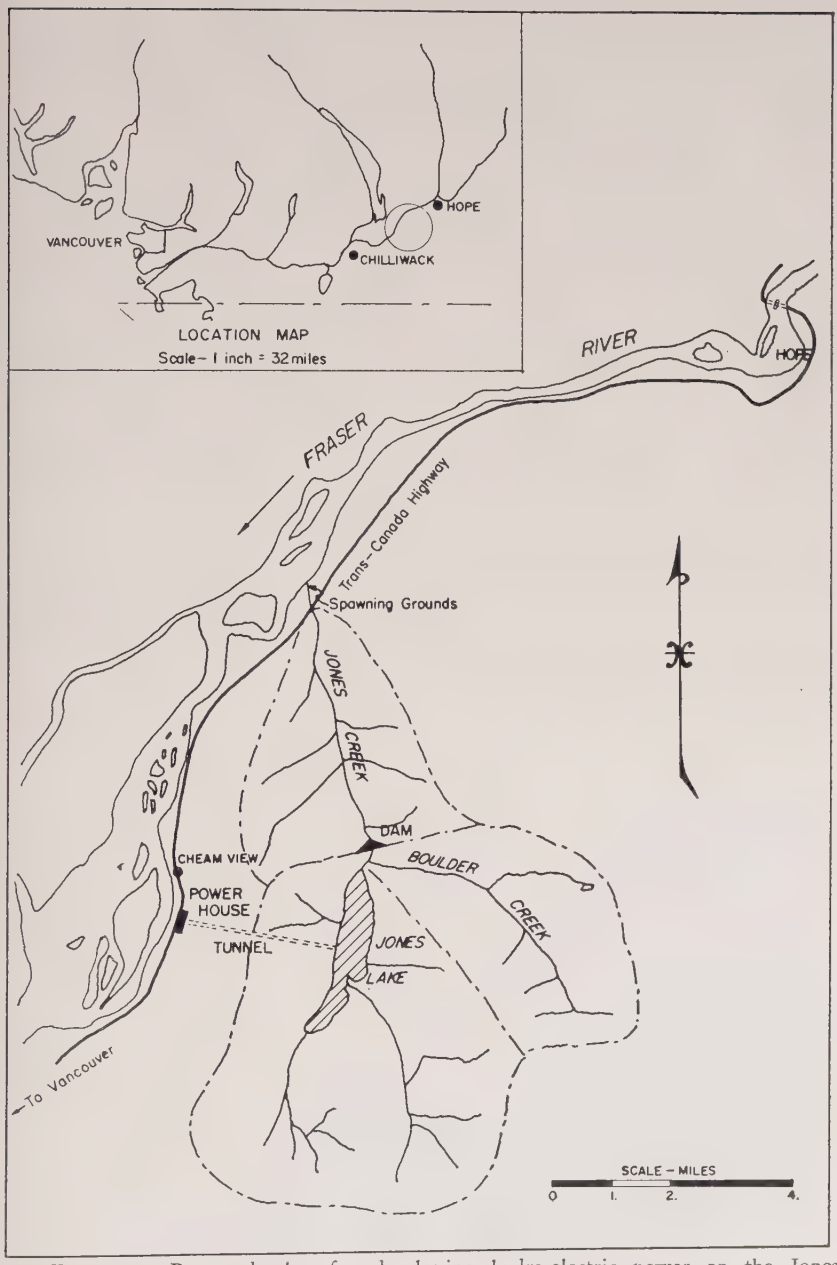

FIGURE 1—Proposed plan for developing hydro-electric power on the Jones Lake system.

odd-number years but also chum salmon *(O. keta)* and a small run of coho salmon *(O. kisutch)* every year. The spawning grounds are confined to the lower one-half mile of the stream.

The diversionary feature of this project was considered the most serious fisheries problem since it meant that the runs would have to be maintained under conditions of severely reduced flow. The first step, therefore, was to determine what the flow would be over the spawning grounds with the proposed development and then decide what measures might be taken to safeguard the fisheries resource.

Engineering and biological surveys began in September of 1949. Gauging stations were installed at the outlet of the lake and at a point just above the spawning grounds. In addition all available hydrographs of the stream for past years were analyzed to obtain the range of variation in discharge. A closed stadia traverse was run from the upstream limit of spawning to the stream mouth. A profile was made of the deepest part of the main channel and cross sections were taken at all places considered to be potential critical sections. The proposed operating schedule of the power plant was also examined with particular reference to the period of filling of the reservoir and the occurrence of periodic spills.

Population estimates of the three species of salmon using the stream were made by tagging and live and dead counts. Sections of the stream utilized for spawning were carefully measured and plotted on a large scale map. Redds were marked and sampled periodically throughout the winter and early spring to determine the period of incubation and time of fry emergence. Fry samples were also taken from the lower reaches of the stream to establish the period of fry migration.

From the engineering data it was established that the drainage area below the proposed dam comprised 20 percent of the total drainage area of Jones Creek and that during the spawning period the minimum residual flow after completion of the dam would be between 5 and 10 cubic feet per second compared to the existing minimum flow of 50 cubic feet per second. Analysis of the cross sections taken over the spawning areas indicated that flows lower than 50 cubic feet per second would leave parts of spawning areas exposed and seriously reduce the depth of water over others.

From discussions with the power company, it was ascertained that the plant would be used primarily for "peaking" purposes, *i.e.* it would be operated during the peak load period of the day throughout the winter months. Normal operation of the plant would be in the morning and evening during the months October to April inclusive. This schedule would have an important effect on the future pattern of flow in Jones Creek. When the plant ceased operation in April the spring and summer runoff would fill the reservoir. In a dry year the runoff from April to October might not fill the reservoir, so that there would be no spill over the dam during this period. In a wet year the reservoir could be

filled before October and the normal flow would then be returned to the creek via the spillway of the dam. In October when water was again diverted to the power plant this spill would soon cease. The hydrograph records indicated also however, that during heavy freshets, which have frequently occurred in November and December, water could again spill from the reservoir even with the plant in operation.

From the biological investigation it was determined that a population of 6,300 pink salmon spawned in Jones Creek in 1949 during the period September 10 to October 30. The chum salmon run was estimated to be 500 adults spawning during the period September 10 to November 20. Coho salmon, estimated to number 200, were observed spawning in the creek from October 5 to January 5.

Total area of gravel used by the pink salmon was 19,600 square feet which gave a mean value of 6.3 square feet per spawning female. Sampling of the redds showed alevins present by January 8 and fry present by April 6. Subsequent observation established that the seaward migration of fry was essentially over by early June.

It was concluded that after the completion of the power project only a small portion of the present runs of salmon could be maintained.

Three possible methods of preserving the run were suggested:

(1) The provision of a minimum flow in the river during the period of spawning, incubation and fry emergence equal to the natural minimum flow of 50 cubic feet per second.

(2) The construction of a new controlled flow spawning channel alongside the present river channel which would be capable of supporting the entire present run. It was estimated that this channel could be designed to operate with an average minimum flow of 20 cubic feet per second.

(3) The provision of a hatchery at Jones Creek capable of handling the entire runs of salmon. It was estimated that the water requirements for such a hatchery could be provided from the residual flow in the stream with the exception that additional amounts of water would be required to attract the adults into the stream and hold them until mature.

These proposals were placed before the power company for consideration. After careful analysis of such factors as water requirements, and capital and operating costs the company, with the Department's approval, elected to proceed with proposal number two, the construction of a controlled flow spawning channel.

Inclusion of this proposal as a method for preserving the runs was based primarily on the experimental work that had been carried out by Wickett (1952) at Nile Creek, where it was indicated that fry production could be significantly increased by controlling the flow of water over the spawning beds during the incubation period.

The basic design of the channel was done by the engineering staff

of the Department. Detailed drawings and construction of the channel were done by the power company. The artificial channel as constructed is approximately 2,000 feet in length and 14 feet in width at the water surface. The difference in elevation between the intake and outlet is 16 feet. Weirs were installed at 100 foot intervals to control the depth and velocity of the water. The drops at these weirs vary between 4 and 12 inches, depending upon topographic and other design considerations. The channel was designed for a depth range of from one to two feet and for a velocity range of from one to two and one-half feet per second. The average flow required for the channel is 20 cubic feet per second, although during the spawning period the flow is increased to between 25 and 30 cubic feet per second and during the incubation period the flow is decreased to about 15 cubic feet per second.

To determine whether the gravel in the excavated channel was suitable for spawning a grading curve derived from sieved samples from known good spawning areas was drawn up. Samples of the channel material were taken throughout its length for comparison with the grading curve. From this analysis it was found that only 200 feet of channel bottom was suitable. It was therefore necessary to deposit gravel to a depth of 12 to 18 inches throughout the balance of the channel. This gravel was washed and graded and ranged in size from one-quarter to one and one-half inches.

The intake works to the channel consists of a low dam across the creek, a Calco gate valve, and a 42 inch pipe through a dyke to the head of the channel. The dam diverts all of the flow in Jones Creek to the artificial channel during low flow periods and at all times the flow is controllable by the Calco gate valve.

The existing channel at Jones Creek is used as a flood channel to by-pass all water over and above the spawning channel requirements. This is an essential feature of the installation and is of particular value during periods of freshet which frequently coincide with reservoir spills. To divert salmon into the spawning channel when there is a flow in the flood channel, a timber weir was constructed across the flood channel just above the outlet of the spawning channel (Figure 2).

To supply water to the channel when the residual flow drops below 20 cubic feet per second, an outlet works of 30 cubic feet per second capacity was installed in Boulder Creek, a tributary to Jones Creek which was diverted into the reservoir. The valve in the outlet works is opened just prior to the cessation of flow from the reservoir. Figure 2 is a schematic diagram of the spawning channel and its appurtenant structures and the grading curve used in establishing the gravel size is shown in Figure 3. Photographs showing the channel under construction and in operation are presented in Figures 4 and 5.

The controlled flow channel and appurtenant facilities were completed on September 16, 1954 and the water was turned on the following day.

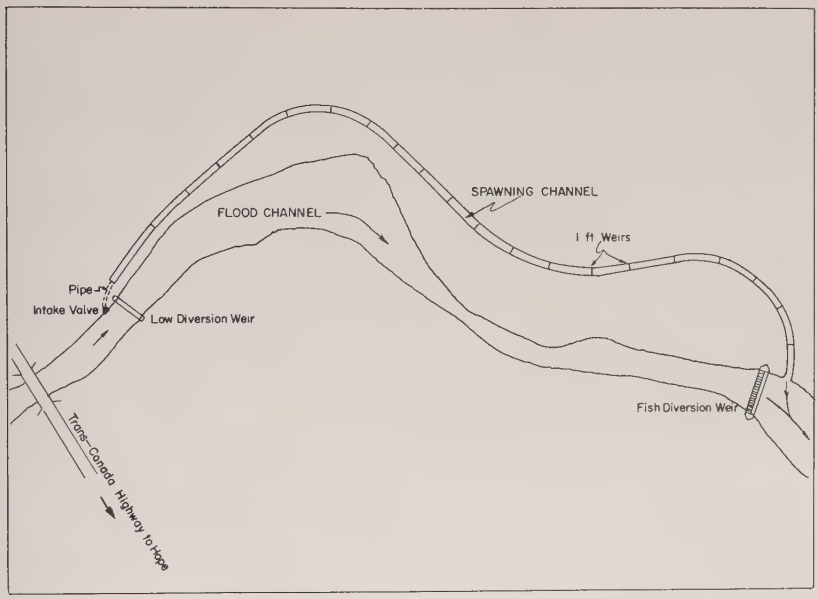

FIGURE 2—Diagram of artificial spawning channel and appurtenant structures.

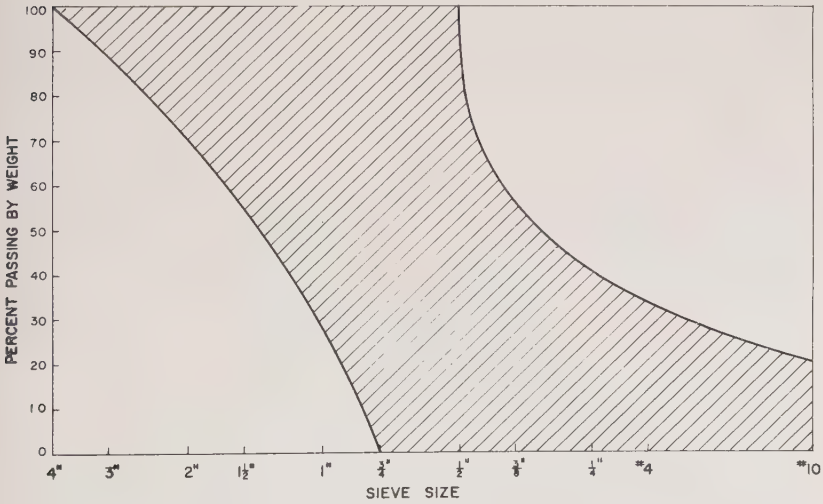

FIGURE 3—Grading curve derived from gravel samples from salmon spawning areas in Adams River[1], Okanagan River, and Jones Creek. The seive analysis of the gravel sample should fall within the cross hatched area.

[1]Courtesy—International Pacific Salmon Fisheries Commission.

FIGURE 4—Channel with 12 inch layer of gravel deposited.

FIGURE 5—Upper end of channel with a flow of 20 cubic feet per second. Note weir in foreground.

When the channel had filled to operating depth it was noted that severe erosion was occurring at the baffle cribs and that the gradient at the channel entrance was too steep. The channel was therefore dewatered to permit modification of the baffle frames. This was completed on September 21 and the channel was again placed in operation. By this date chum salmon had entered Jones Creek and were observed immediately below the channel entrance. Further observations of their behavior indicated that conditions at the channel entrance were not suitable for their access and as a result they were spawning in the stream below. This necessitated a further shutdown of the channel to permit extensive modification of the entrance. This was not completed until October 15, by which date chum salmon spawning was essentially over and none of this species entered the channel. On November 4 three coho were observed in the top section of the channel and by November 20 a total of 28 had entered and spawned in the upper sections.

The principal use made of the controlled flow channel in 1954 was in connection with the planting of "eyed" Skeena River pink salmon eggs, described by Neave and Wickett (1955).

Since the expected run of pink salmon in 1955 would provide the first real test of the channel special preparations were made to study the behavior of the spawners. To establish depth and velocity preferences three complete depth-velocity cross sections were made in each section of the channel. Since the first fish to arrive would have a large choice of spawning sites the depth and velocity chosen should point out their preference. Large scale maps of the channel were therefore prepared so that as the fish arrived their positions could be plotted along with the date of commencement of redd building. In addition to the cross sections, spot depth and velocity measurements were made at six standard points in the upper 15 of the 18 channel sections and additional points were measured in the upper two sections. A steel "finger trap" was installed in the lower section of the channel to permit the recovery of all dead spawned salmon for examination and enumeration.

Sections of seine webbing were placed over several areas of the channel to study cover requirements.

The first pink salmon entered the channel on September 13 and these moved to the upper end and began spawning. Daily counts of live salmon were made in each section of the channel and the positions of the first 100 pairs of spawners were plotted on the large scale map for the depth and velocity preference studies. A count was made of all dead fish recovered at the "finger trap" and each fish was examined for sex and degree of completeness of spawning.

In all a total of 400 pink salmon and 160 chum salmon spawned in the channel during the period September 13 to November 2. The male to female ratio established from count of dead salmon was 37:63 for the pink salmon and 42:58 for the chum salmon. Based on an average

fecundity of 1,700 eggs in a female pink salmon and 2,700 eggs in a chum salmon (Neave, 1953), a total of 428,000 pink salmon eggs and 251,000 chum salmon eggs were calculated to have been available for deposition in the channel.

The following observations were made with reference to spawning density, depth and velocity preferences, and cover requirements:

(1) Due to the small size of the run there was never any population pressure exerted on the spawners and the maximum density was only one pair to every five square yards.

(2) The first fish to spawn in any section chose a spawning site that was deeper than the mean depth of those sites chosen in that section during the first week. This mean depth of spawning sites chosen during the first week was in turn generally greater than the mean depth available in the same section.

(3) The first fish in any section chose a spawning site with a lower velocity than the mean velocity of those sites chosen in that section during the first week of the run. This mean velocity of spawning sites chosen during the first week was in turn generally lower than the mean velocity available. This information is summarized in Table 1 and it will be noted that the five sections that were completely unused by the first 100 spawning pairs were considerably shallower and faster than those sections that were occupied.

(4) Cover, that is, protection against direct exposure appeared to play an important role in the selection of spawning sites. The best cover on the stream was at the outlet of the intake where the water was deep and relatively turbulent. This was the most heavily spawned section. Further evidence of the role of cover appeared in the observation that the first redd sites of each section were immediately above the weir. The fish were observed to hide in the deeper more turbulent water below these weirs and commence digging above.

To determine the number of fry produced from the deposited eggs a Wolf fry trap was installed in the lower section of the channel. The trap was placed in operation on April 17, 1956. All fry collected in the live box were removed with a dip net, identified, counted, and released into the channel below. This operation was carried out from 10:00 p.m. to midnight and from 6:00 a.m. to 8:00 a.m. From April 17 to July 2 a total of 157,933 pink fry and 75,155 chum fry were counted through the trap. This represents a survival of 37 percent and 30 percent respectively of the eggs available for deposition. When it is considered that natural survival as determined by Fisheries Research Board experiments at Port John, Nile Creek, and Masset ranged from less than 1 percent to 23 percent with a mean of 11 percent, the value of the controlled flow channel becomes apparent. The fact that the run to the creek was small was no doubt partially responsible for the high survival. It was attained, however,

TABLE 1—*Depth and velocity preferences of spawning pink salmon in the artificial spawning channel - 1955.*

Section	Velocity (feet per second)			Depth (feet)		
	Available	First 100 mean choice	First days choice spawning in each section	Available	First 100 mean choice	First days choice spawning in each section
1	2.0	2.0	2.1	1.04	0.99	1.07
2	1.6	1.8	1.4	1.23	1.19	1.33
3	1.7	1.8	1.3	1.20	1.18	1.41
4	2.1	2.0	1.4	1.25	1.25	1.30
5	2.9	2.4	2.2	1.10	1.17	1.20
7	2.2	1.8	1.6	1.39	1.49	1.50
8	2.4	2.0	1.5	1.19	1.30	1.50
9	2.4	1.7	1.7	1.10	1.36	1.45
10	2.6	No fish	No fish	1.07	No fish	No fish
11	3.2	No fish	No fish	1.01	No fish	No fish
12	2.9	No fish	No fish	1.03	No fish	No fish
13	2.6	No fish	No fish	1.10	No fish	No fish
14	2.4	No fish	No fish	1.06	No fish	No fish
15	1.9	1.5	1.5	1.33	1.57	1.65
Average	2.1	1.9	1.4	1.20	1.28	1.38

in the face of extreme freshet conditions which occurred on November 3, 1955 during which the discharge in the flood channel exceeded 1,800 cubic feet per second.

The results of the first year's operation of the channel are considered encouraging and certain modifications in connection with silt control indicate that survival could be increased. In general it is felt that this type of installation will be of value, not only in association with power developments but also as a fish culture technique for increasing the production of salmon.

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REPRODUCTION OF LAKE TROUT IN ALGONQUIN PARK, ONTARIO

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ABSTRACT

In lakes of Algonquin Park, Ontario, lake trout *(Salvelinus namaycush namaycush)* spawn on clean, wave swept shoals of broken rubble ranging from 1½ to 4 inches in diameter and in water from 6 inches to 12 feet deep. Weather conditions may influence the time and duration of the reproductive period but it most often occurs in the last half of October and lasts about 10 days. Water surface temperatures are usually between 50 and 55°F. Spawning occurs chiefly at night from sunset to about 10:30 p. m. Nightly counts were made of the fish on the beds during spawning in Lake Louisa in 1947. Courtship behaviour is described. Males made up 60-85 percent of the spawning population. The size composition of the spawning population varied markedly from lake to lake because of different growth rates. The smaller trout spawn first.

Egg frequency estimates on the spawning beds averaged 50 per square foot. *Saprolegnia* infection of the eggs on the beds appears to be the main cause of egg mortality. Northern brown bullhead *(Ameiurus nebulosus)* and Menominee whitefish *(Prosopium cylindraceum quadrilaterale)* were the chief egg predators. Water level drawdowns in late fall and winter may expose some eggs and make large areas of potential beds unavailable for spawning.

Time of hatching ranges from mid-February to late March, an incubation period of 15 to 21 weeks. The fry leave the spawning beds by at least mid-May.

DESCRIPTION OF SPAWNING GROUNDS

Lake trout, *Salvelinus n. namaycush,* in the Algonquin Park area spawn on rocky shoals. Prominent points and islands facing the prevailing westerly winds are favoured as are submerged or partially submerged mid-lake shoals. Figure 1 shows the location of known spawning beds in Lake Louisa.

Broken rock or rubble mostly 1½ to 4 inches in diameter and commonly mixed with large boulders make up these shoals. This rubble is usually a foot or more thick and sand, mud, or detritus are absent. There is no evidence of currents, springs, or local temperature differences in the region of the beds at any time of the year. A typical spawning bed, exposed by low water level, is shown in Figure 2.

Size of individual spawning beds examined varied from 15 to about 1,500 square yards. In Louisa (1,480 acres), Hay (2,800 acres), and

FIGURE 1.—Location of known lake trout spawning beds in western end of Lake Louisa, Ontario. One spawning bed located at extreme eastern end of Lake is not shown.

Shirley (1,200 acres) lakes there were 11, 5, and 2 known spawning beds respectively, which had total areas of 1,200, 125, and 100 square yards.

Depth of water over the spawning beds ranged in Lake Louisa from 6 inches to 8 feet; in Hay and Shirley lakes from 1 to 5 feet; in Happy Isle Lake from 2 to 6 feet; in Merchants Lake from 1½ to 4 feet; and in Lake Opeongo from 2½ to 12 feet.

For comparison some other recorded information on depths of lake trout spawning is summarized in Table 1. It will be noted that lake trout are reported to spawn in depths from a few inches to 200 feet. In general, spawning becomes deeper with increasing lake size probably because of deeper shoals and greater wave action. In the smaller lakes spawning is usually in less than 15 feet of water.

TIME OF SPAWNING

Lake trout spawning in Algonquin Park lakes usually occurs in the last half of October although it has begun as early as October 10 and extended to as late as November (see Table 2). The duration of the

TABLE 1.—*Summary of recorded data on lake trout reproduction*

Location	Authority	Depth of spawning (feet)	Time of spawning	Duration of spawning (days)	Temperature at spawning	Time of hatching	Length of incubation
New York State							
Otsego Lake	Royce (1951)	2-15	Late November-early December	—	Time of overturn	Mid-April	—
Senaca Lake	Royce (1951)	100-200	Late September-October	—	Before overturn surface 57-62°F	Late January	4 months
Raquette Lake	Royce (1951)	Less than 10	Mid to late October	5-12	Time of overturn	—	—
Lake George	Royce (1951)	—	Early November	7-10	—	—	—
Cayuga Lake	Galligan[1]	100-150	September 20-November 8	—	—	—	—
New Hampshire							
Squam Lake	Merriman (1935)	½-10	Mid to late October	7-10	Surface 42°F	—	—
Ontario							
Lake Simcoe	Rawson (1930) McCrimmon (1956)	15-20	Mid to late October	—	—	—	—
Lake Wanipitei	Whitfield[2]	1-10	Mid October	—	—	February 25	135 days
Lake Nipigon	Dymond (1926)	—	October	—	—	—	—
Quebec							
Commandant Lake	Atkinson (1931)	—	October 21-November 11	—	Surface 51°F	—	—
Saskatchewan							
Lac La Ronge	Rawson & Atton (1953)	—	October 8-15	—	Surface 48°F	—	—
Alberta							
Pyramid Lake	Rawson & Elsey (1950)	7-25	October 3-22	—	Surface 51°F	—	—
Lake Minnewanka	Rawson[3]	15-30	Early October	—	Surface 51°F	May	—
North West Territories							
Great Bear Lake	Miller & Kennedy (1948)	10-20	Early August	—	—	—	—
Great Lakes							
Superior	Eschmeyer (1955)	Less than 120	October-early November		—	—	—
Michigan	Van Oosten (1935)	—	October 10-November 15	—	—	—	—
Huron	Van Oosten (1935)	—	October 10-November 21	—	—	—	—

[1]Galligan, J. P. 1951. The distribution of lake trout and associated species in Cayuga Lake. M.Sc. Thesis, Cornell Univ.
[2]Whitfield, R. 1949. Lake Wanipitei fishery investigation. Ontario Department of Lands and Forests.
[3]Rawson, D. S. 1945. Further investigation of the effect of power development on the fisheries of Lake Minnewanka, Banff. Typewritten report submitted to the National Parks Bureau, Department of Mines and Resources, Ottowa, Canada.

spawning period has varied from 5 to 13 days but on the average lasts about 10 days.

These variations in time and duration of the spawning period appear to be associated with meteorological conditions as wind, light, and temperature. Lake trout usually first appear in the general region of the spawning beds in early October when water surface temperatures are in the middle to high fifties. The sudden onset of dull, cold, or windy weather and a drop in water temperatures may precipitate a movement of the trout onto the spawning grounds and the whole spawning act may be over in a few days. This happened in Lake Opeongo in 1948 when four successive days of such weather resulted in spawning being early and of short duration (see Table 2). On the other hand bright, calm, warm weather may delay and prolong the reproductive period as occurred in Lake Louisa in 1947 when trout were seen on the beds for a period of nearly four weeks (October 10 to November 4) and spawning itself was later than usual and of longer duration. October and early November weather was exceptional in 1947; bright, calm, warm weather prevailing on all but a few days. In 1949 the Opeongo lake trout moved to deeper water for nearly a week when surface temperatures climbed to 60 degrees in mid-October.

TABLE 2.—*Approximate time and duration of spawning of lake trout in certain Algonquin Park lakes for the period 1946–1956 and water surface temperature at beginning of spawning*

Year	Lake	Spawning period	Duration of spawning (days)	Water surface temperature °F	Thermocline
1946	Smoke	Oct. 21-Nov. 1	11	50 (Oct. 18)	Absent
1947	Louisa	Oct. 25-Nov. 7	13	53 (Oct. 24)	Present
1948	Opeongo	Oct. 10-Oct. 15	5	54 (Oct. 13)	Present
1949	Opeongo	Oct. 23-Nov. 5	13	56 (Oct. 15)	Absent
1949*	Hay	Oct. 15-Oct. 25	10	56 (Oct. 18)	Present
1950	Louisa	Oct. 15-Oct. 25	10	52 (Oct. 19)	—
1950*	Shirley	Oct. 18-Oct. 27	9	48 (Oct. 22)	—
1950*	Opeongo	Oct. 20-Oct. 30	10	—	Present
1951	Louisa	Oct. 20-	—	53 (Oct. 10)	Present
1951	Opeongo	Oct. 20-	—	—	—
1953	Opeongo	Oct. 16-Oct. 25	9	51 (Oct. 17)	—
1954	Shirley	Oct. 20-	—	52 (Oct. 20)	—
1954	Opeongo	Oct. 15-	—	52 (Oct. 17)	—
1955	Shirley	Oct. 20-Oct. 28	8	—	—
1955	Opeongo	Oct. 18-Oct. 25	7	52 (Oct. 18)	—
1956	Louisa	Oct. 15-Oct. 27	12	51 (Oct. 10)	Absent
1956	Shirley	Oct. 10-Oct. 21	11	52 (Oct. 16)	Present
1956	Opeongo	Oct. 12-Oct. 20	8	50 (Oct. 13)	Present
1956*	Merchants	Oct. 15-Oct. 23	8	52 (Oct. 17)	Absent
1956*	Happy Isle	Oct. 12-Oct. 22	10	52 (Oct. 16)	Present

*Estimated times on basis of single observation.

Royce (1951) has shown a correlation in New York State lakes between the amount of cloudiness in the three months before spawning, the autumnal drop in temperature, the depth of the lake, and time of spawning. It is not known to what extent these relationships are true in Algonquin Park lakes. Wind, light, and temperature conditions immediately prior to spawning and at a time when lake temperatures are approaching the low fifties seem to trigger spawning within fairly narrow limits of time. There does not seem to be any relationship between

FIGURE 2.—Portion of typical lake trout spawning bed exposed because of low water levels, Hay Lake, Ontario.

the fall overturn and time of spawning (see Table 2) as has been noted by Royce (1951) in certain New York lakes.

Lake trout throughout their range may spawn from early August to early December but in the smaller inland lakes it is usually in mid to late October (see Table 1).

PRE-SPAWNING ACTIVITIES

Lake trout appear on the spawning beds chiefly at night. To observe them illumination was provided by a Coleman lantern fitted with a reflector. A standard automobile sealed-beam headlight fitted on an alumi-

num pole was also particularly useful because it was waterproof and could be operated underwater, thus eliminating surface reflections. Netting and observations indicated few trout occurred on the spawning beds in the daylight hours as was also noted by Merriman (1935) and Royce (1951).

Lake trout appear to move on to the beds en masse since as many are there by 6 or 7 p.m. as later in the evening. The numbers present remain fairly constant through 10 or 10:30 p.m. After this time there are few trout on the spawning areas at least until 1 a.m., the latest point at which observations were carried out.

In 1947 cleaning of the spawning beds by the trout was first noted in Lake Louisa on October 16. This action consists of a twist of the tail or body over the bottom or occasionally rubbing with the snout the interstices between the rocks. This action was seen on surprisingly few occasions considering the size of the areas eventually cleaned by the fish.

Estimates were made of the maximum numbers of spawning lake trout on the beds each night in the period October 15 through November 4, 1947 in Lake Louisa. There was a gradual increase in numbers during the October 15-25 period followed by a sudden increase on the beds about October 25 (see Table 3).

There was some variation in the numbers of fish on the beds. The date of maximum numbers varied from bed to bed in 1947 and observations carried out in 1950 and 1956 in Louisa indicated beds may be used in varying degrees in different years. On area 9, which was the most important spawning ground in 1947, there was a maximum of about 10 fish in 1950 and about 30 in 1956. Area 8 was more extensively used in these years.

After the maxima were reached there was in general a steady decrease in numbers. By November 4 only a few trout were still on the beds.

Courtship and Spawning Behavior

In Lake Louisa in 1947 the first indication of courtship or spawning was noted on October 23 when one trout was seen following another. On the following nights males were seen following females for a distance of 15 to 20 feet, often preceding this action by butting the female's side with his snout. Sometimes the male zig-zagged back and forth underneath the female brushing her in the region of the vent with his back and dorsal fin. In all cases the female swam away from these attentions. A male did not restrict his actions to any one female but courted any that came within range. At about the same time shiny dark bands appeared on the sides of the males and dark areas around the heads. This colouration permitted easy visual distinction between the sexes.

The spawning act itself was not seen in spite of repeated efforts to observe it. It is thought the illumation of the beds somewhat inhibited

TABLE 3.—*Approximate maximum numbers of lake trout seen on spawning beds in Lake Louisa, 1947. See Figure 1 for location of spawning areas. All observations between 6 and 10 p.m. except where indicated*

Date	Spawning Area 1	2	3	4	5	6	7	8	9	10	11	Remarks
October												
15	2	9	5	—	—	—	—	—	—	—	—	
16	—	6	—	10	9	4	—	—	—	—	—	Cleaning first noted
17	1	3	—	10-15	6	—	—	—	—	—	—	
18	—	1	—	10-15	0	—	—	—	—	—	—	
21	—	10	—	30-40	—	—	—	—	—	—	—	
23	—	15	—	10-12	—	—	—	—	—	—	—	Beginning of courtship
24	—	15	—	10-15	—	25-30	—	—	—	—	—	
25	10-15	100-125	—	15	5	50	—	—	—	—	—	Male colouration. Beginning of spawning
26	—	50	—	15	—	—	20-30	20	—	—	—	
27	—	5 (10:30 p.m.)	—	—	—	—	—	—	150-200	50	6	
28	—	20-25	—	—	—	20	—	—	75-100	—	—	
29	—	10-15 (12:30 a.m.)	—	—	—	0 (12:30 a.m.)	—	—	3 (12:30 a.m.)	—	—	
30	—	25-35	—	—	—	—	10	—	50-75	—	—	
31	—	—	—	—	—	—	—	—	40-50	—	—	
November												
2	—	30-40	—	—	—	—	—	10	10-20	—	—	
3	—	—	—	—	25-35	10-15	—	—	10-20	—	—	
4	—	10-15	—	—	2	6	—	—	—	—	—	

the fish. The exact time of first oviposition in Lake Louisa in 1947 is not known but from the numbers of trout on the beds and their behaviour it was likely about October 25.

Sex Ratios

Milling of the spawning lake trout made counting and determination of the sexes difficult. Netting in 1947 indicated males made up 65 to 75 percent of the spawners in Lake Louisa. Of the 200 fish sexed during the tagging of lake trout on the spawning beds in Louisa in 1951 and 1956, 85 percent were males. In lake trout tagging carried out on the spawning beds in Lake Opeongo in 1948, 1949, and 1950 males formed 60 to 80 percent of the total catch. These proportions of males in the spawning population are similar to those reported by Eschmeyer (1955) from Lake Superior and Royce (1936) from New York State lakes.

Size Composition of Spawning Population

About three-quarters of the spawners in Louisa and Shirley lakes were 13 to 15 inches long and in Lake Opeongo 17 to 21 inches long (Table 4). As has been shown by Martin (1952) trout in lakes such as Louisa and Shirley are typically slow growing because they feed mostly on

Table 4.—*Length frequencies of spawning lake trout, Lake Louisa, Shirley Lake, and Lake Opeongo, based on gill-net samples from spawning grounds.*

Fork Length (inches)	Louisa 1947		Louisa 1956		Shirley 1954		Opeongo 1949	
	Male	Female	Male	Female	Male	Female	Male	Female
11	6	..	3	..	1	..	..	..
12	6	..	27	..	3	..	..	..
13	27	2	42	9	3	3	..	..
14	21	11	43	9	9	7	1	..
15	4	2	37	8	2	5	2	..
16	1	1	8	4	1	1	5	1
17	1	..	2	1	1	..	17	3
18	1	..	..	..	1	..	17	4
19	..	..	..	..	2	..	12	10
20	..	..	..	..	..	..	17	7
21	..	..	..	..	..	..	11	4
22	..	..	..	..	..	..	5	2
23	..	..	..	..	..	..	5	1
24	..	..	..	..	..	..	5	1
25	..	..	..	..	..	..	1	2
over 25	..	..	..	..	..	..	7	6
Number examined	67	16	162	31	23	16	105	41
Average length	13.3	14.1	13.7	14.3	14.4	14.3	19.8	20.8

plankton. In lakes such as Opeongo where they are essentially fish feeders the lake trout grow more rapidly and reach a larger size.

Night observations in Louisa in 1947 suggested there was an increase in the average length of the spawning trout as the spawning season progressed. Netting operations confirmed this. Male trout in Louisa in 1947 averaged 12.9 inches in the October 12-13 period, 13.3 inches in the October 16-21 period, and 13.8 inches in the October 24-November 2 period. In addition occasional large trout (over 16 inches) were seen only during the latter part of the spawning run. Miller and Kennedy (1948) and Royce (1951) also noted smaller fish spawning in the early part of the run in Great Bear Lake and in New York State lakes.

Distribution of Eggs on Spawning Beds

Exposure of spawning beds due to falling lake levels has allowed an opportunity to make counts of distribution of eggs. In Hay Lake 16 eggs were located in an area of 15 square feet, 114 eggs in a 6-square foot area, and 15 and 50 eggs in two 1-square foot areas.

Pails and trays buried in the beds before spawning provided additional data on egg distribution. In screened trays, six feet square, in Shirley and Louisa lakes there were 188 and 63 eggs respectively. Ordinary 2½-gallon perforated water pails were buried in the artificial spawning bed constructed in Shirley Lake in 1954 (Martin, 1955). Eggs were found in 16 of the 20 pails in numbers ranging from 4 to 276 per pail. The mean figure was 66 per pail. It is estimated that 43,000 eggs were deposited on this 450 square-foot bed.

An average for all the above counts in Hay, Louisa, and Shirley lakes is approximately 50 eggs per square foot. This compares with an estimate of 20 to 50 per square foot made by Royce (1951) in Otsego Lake, New York.

Causes of Egg Loss

Fungus Infection

A high percentage of the eggs on the spawning beds may be infected by *Saprolegnia*. As high as 80 percent of eggs pumped from the spawning beds have been found to be infected. In Lake Louisa in March, 1951, 57 of 65 eggs and yolk sac fry taken from a spawning tray were infected with fungus.

Data on egg survival from 20 pails buried in the artificial spawning bed in Shirley Lake in 1954-5 is shown in Table 5.

About half of the dead eggs in each of the periods were infected with *Saprolegnia*. As it is difficult to determine the stage of development of the eggs when infected, the figures may not be too reliable. But it is evident that considerable numbers reach the eyed-egg stage

TABLE 5.—*Lake trout eggs collected from pails buried in artificial spawning bed in Shirley Lake, Algonquin Park, Ontario, 1954–1955.*

Date	Number of pails examined	Pails with eggs	Total eggs	Percent dead eggs	Percent of dead eggs *Saprolegnia* infected	Percent of *Saprolegnia* infected eggs		
						Not fertilized	Infected before eyeing	Infected at eyeing
November 8, 1954	3	3	350	11	51	—	—	—
January 19, 1955	11	9	689	36	42	43	26	33
February 9, 1955	6	4	289	53	55	45	31	24
Total	20	16	1328	38	48	44	28	28

TABLE 6.—*Number of fish examined and number containing lake trout eggs during spawning in Algonquin Park, Ontario, Lakes.*

Lake	Year	Lake trout	Brown bullhead	White sucker	Lake whitefish	Menominee whitefish	Smallmouth bass	Burbot
Smoke	1946	15-0	9-1	5-0	36-0	—	2-0	4-0
Louisa	1947	40-1	—	1-0	—	—	—	—
Opeongo	1948	10-1	—	—	—	—	—	—
Opeongo	1949	40-2	12-8	5-0	10-0	—	—	—
Opeongo	1950	2-0	—	—	—	—	—	—
Shirley	1950	9-0	1-1	8-0	—	—	—	—
Louisa	1950	13-0	—	—	—	—	—	—
Louisa	1951	10-0	—	—	—	—	—	—
Opeongo	1951	22-2	—	—	—	—	—	—
Shirley	1951	9-0	—	—	—	—	—	—
Opeongo	1953	2-0	4-3	5-0	23-1	6-5	—	—
Opeongo	1954	—	15-10	—	20-0	1-1	—	—
Shirley	1954	—	—	5-0	—	—	—	—
Totals		172-6	41-23	29-0	89-1	7-6	2-0	4-0

before infection. As temperature and oxygen conditions were no different in the pails than outside and the degree of infection in the pails was not related to numbers of eggs, it appears that the foregoing data give some indication of natural mortality of eggs on the spawning areas.

The question arises as to whether the *Saprolegnia* is a primary cause of egg mortality or whether it only infects eggs that have previously died of other causes. Undoubtedly the fungus first attacks dead eggs but hatchery experience indicates it will rapidly and extensively infect live eggs. The scope of the infection on the beds also encourages the belief that the fungus is the primary cause of death in many cases.

Predation

The stomach contents of lake trout and other fish near the spawning beds were examined for trout eggs. The results are summarized in Table 6.

The lake trout is apparently not a serious predator on its own eggs in Algonquin Park lakes. Other investigators (Rayner, 1941; Rawson and Elsey, 1950; Royce, 1951, Galligan) have noted that lake trout, particularly the juveniles, may feed on trout eggs.

Brown bullheads *(Ameiurus nebulosus)* were the chief predators on trout eggs in the lakes studied. In Hay Lake in 1953, when low lake levels forced the trout to spawn on rubble offering little protection to the eggs, hundreds of bullheads were seen feeding on trout eggs. Atkinson (1931) also noted heavy predation by this fish in Commandant Lake, Quebec. Contrary to the findings of other workers (Atkinson, 1931; Greene, Hunter, and Senning, 1932; Simpson, 1939; Rayner, 1941; Galligan) suckers do not appear to be a serious predator on lake trout eggs in Algonquin Park lakes.

The Menominee whitefish *(Prosopium cylindraceum quadrilaterale)* may be a serious predator on lake trout eggs in Lake Opeongo although the lake whitefish *(Coregonus clupeaformis)* is not.

Egg predation is very low in Lake Louisa. Other than the suckers, there are no potential egg predators present in the lake and only two suckers have been seen on the beds during the numerous observations in this lake over a period of years.

Water Level Fluctuations

Some loss of lake trout eggs has been observed in Algonquin Park lakes because of water level draw-downs in the late fall and winter for hydro-electric power purposes (Martin, 1955). On the whole this loss has not been important. In Shirley and Hay lakes draw-down has left considerable areas of potential spawning grounds exposed before the spawning season. An estimated 200 square yards of beds may so be-

TABLE 7.—*Incubation period of lake trout eggs in certain Algonquin Park, Ontario lakes.*

Lake	Year	Approximate time of spawning	Approximate time of hatching	Approximate incubation period (weeks)
Louisa	1947-8	Oct. 24—Nov. 4	March 30	20
Shirley	1950-1	October 18-27	March 30	21
Louisa	1950-1	October 15-25	March 20	19
Opeongo	1950-1	October 20-30	March 20	19
Hay	1953-4	October 20-30	February 20	16
Louisa	1953-4	October 20-30	February 15	15

come unavailable to the lake trout in Shirley Lake in some years.

Whitfield estimated an average yearly loss of 26.3 percent of lake trout eggs in Lake Wanipitei, Ontario, because of water level drawdowns. Cuerrier (1954) on the other hand found greater vertical distribution of spawning after the raising of water levels by the construction of a dam on Lake Minnewanka.

INCUBATION AND HATCHING

Incubation period of lake trout eggs in some Algonquin Park lakes is shown in Table 7. Date of hatching varies considerably but usually occurs in late March. On the basis of these observations it appears that the period of incubation may vary from 15-21 weeks.

In 1953-4 the length of the incubation period was 15-16 weeks or about five weeks shorter than usual. Water temperatures in late November and early December in 1953 averaged five degrees warmer than usual for that period and probably hastened the early development of the eggs.

Scattered temperature and oxygen records have been taken from the spawning beds during the incubation period. During January and February temperatures of 32.5°F. and 33.8°F. have been recorded on the beds, and oxygen concentrations of 8 to 8.5 p.p.m.

According to the literature, time of hatching has varied considerably throughout the lake trout range (Table 1). It has been reported as early as January in Seneca Lake, New York and as late as June in Great Bear Lake of northern Canada. The usual incubation period is four to five months.

FRY AND JUVENILE LAKE TROUT

Several attempts have been made to capture lake trout fry to determine when they leave the spawning beds. These have been unsuccessful because this period coincides with the beginning of the breakup of the ice. By

use of aqua-lungs in Lake Opeongo indications were found that the fry had left the spawning bed before mid-May. Royce (1951) experienced similar difficulties but believes the fry may desert the spawning beds in New York State lakes in the period May 20-25.

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TOXICITY OF DIELDRIN TO FISH

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ABSTRACT

Toxicity bio-assays of run-off water from an area treated with dieldrin at the rate of 4.66 pounds per acre indicated that the run-off from the first rain following treatment was toxic to fathead minnows, *Pimephales promelas,* at a dilution of one in three. Mortality in run-off from the third rain was less than 50 percent, and a few fish exhibited the characteristic effects of dieldrin when placed in run-off from the fourth rain following treatment. It is evident that run-off from an extensive area treated with dieldrin would adversely affect fish life.

A time-of-effect concentration curve was prepared by exposing fish to known concentrations of dieldrin. Tests with samples, the concentrations of which were unknown to the investigators, indicated that within the range of 0.03 to 0.5 p.p.m., the dieldrin concentration could be estimated within 25 percent. By using this curve it was estimated that the composite sample of run-off contained 0.128 p.p.m. of dieldrin.

Bio-assays with different formulations of dieldrin showed that it was extremely toxic to three different species of fish. The 96-hour TL/m values ranged from 0.0056 to 0.042 p.p.m., depending on the formulation and the kind of fish.

Tests, when using dilution waters with different characteristics, indicated that dieldrin was somewhat more toxic in hard than in soft waters. While larger volumes per fish of the test solution appeared to be slightly more toxic, evidence was not sufficient to establish that absorption of dieldrin by fish reduced the toxicity of test solutions.

INTRODUCTION

Increased interest is being shown in the effect of newer organic insecticides on fish and wildlife. Investigations have been made into a variety of problems in many sections of the country (Ingram and Tarzwell, 1954). Run-off from areas treated with insecticides has been reported to be responsible for large scale destruction of aquatic life in many streams and farm ponds (Young and Nicholson, 1951; Hoffman and Drooz, 1953). Doudoroff, Katz, and Tarzwell (1953) studied the toxicity of dusts containing aldrin, toxaphene, and a BHC-DDT mixture; they reported that aldrin and toxaphene were extremely toxic to fish. Water extracts of soil samples taken from cotton fields treated several months previously with toxaphene were also found to be toxic to fish. This persistence of insecticides in soils, and the toxicity of run-off water is of concern to water-

users and fish managers. Information is needed on those insecticides tied up in the soil so that the run-off is non-toxic, and on those which are not adsorbed, tied up, or inactivated.

Cooperative studies to determine the toxicity of run-off waters from an area treated with dieldrin[1] were carried out in 1954 at the Lawson General Hospital near Atlanta, Georgia. The hospital grounds were infested with white fringed beetles and in need of insecticidal treatment. The U. S. Department of Agriculture, Cereal and Forage Insect Investigations Laboratory at Macon, Georgia, had conducted studies with dieldrin with promising results. They desired to continue the studies and learn something of the pollutional effects of soil applications of dieldrin. Arrangements were made whereby the Macon laboratory would direct the application of the necessary quantities of dieldrin, the Public Health Service Regional Office at Atlanta, Georgia, would make the necessary measurements of rainfall and run-off, and would collect and ship the run-off samples to the Robert A. Taft Sanitary Engineering Center where bio-assays would be made to determine toxicity to fish.

In addition to toxicity determination, information was also desired on the dieldrin content of run-off waters. Because methods of chemical analysis at the time were not considered adequate, it was decided to use fish for estimating the amount of dieldrin in run-off water. Several investigators have used living organisms for detecting and estimating small quantities of chlorinated hydrocarbon insecticides in foods and other materials. Among organisms which have been used are mosquito larvae (Bushland, 1951), houseflies (Sun and Sun, 1952), and goldfish (Davidow and Sabatino, 1954). It was believed that by properly using bio-assays to establish a time-of-effect concentration curve, small amounts of dieldrin could be detected and quantities estimated with a reasonable degree of accuracy. Studies were made to determine the feasibility of this method.

Dieldrin has been used in a variety of ways and in several different formulations. Run-off from treated areas may enter a variety of streams with different water quality characteristics and fish populations. Therefore, laboratory bio-assays were made to determine the effect of several dieldrin formulations on three common species of fish in dilution waters with a wide range of quality characteristics.

Bio-assay Methods

Bio-assays were carried out in accordance with the methods suggested by the Sewage and Industrial Waste Sub-committe on Toxicity (Doudoroff

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[1]Dieldrin is the common name given to the chlorinated hydrocarbon insecticide containing not less than 85 percent of the compound HEOD and not more than 15 percent of active related compounds. Chemically, HEOD is 1, 2, 3, 4, 10, 10-hexachloro-6, 7-epoxy-1, 4, 4a, 5, 6, 7, 8, 8a-octahydro-1, 4-endo, exo-5, 8-dimethanonaphthalene. Technical flake dieldrin, the commercially available product, contains 90 percent dieldrin.

et al, 1951). Exploratory tests were made in one-gallon widemouth glass jars using two fish in two liters of solution to determine the approximate range of toxicity. Generally, full scale experiments were set up in five-gallon wide-mouth glass jars using five fish in 10 liters with duplicates set up for each concentration. In carrying out the bio-assays, necessary test concentrations were prepared, fish added, and observations made for at least 96 hours. Chemical tests for dissolved oxygen, pH, alkalinity, hardness, and free CO_2 were made at the beginning of the experiment, and again after the death of all fish in any concentration or at the termination of the experiment. The bio-assays were made in a constant-temperature room at 22°C. Controls were set up by placing the same number of fish in jars containing only dilution water. If more than 10 percent of the control fish were lost, the experiment was discontinued and repeated.

In each experiment different concentrations of dieldrin, usually quarter points on a log-scale (e.g., 100, 56, 32, 18, and 10 percent), were tested. The TL_m (median tolerance limit-concentration that kills 50 percent of the fish) values were obtained by straight line graphic interpolation using semi-logarithmic paper for 24, 48, and 96-hour periods.

During the course of all following experiments, dissolved oxygen values were adequate for the support of fish. All values were over 4 p.p.m., and in most test concentrations values were from 6 to 8 p.p.m. at the end of the experiments. The pH values dropped slightly in some experiments, probably due to increased CO_2 content, but in all test concentrations they were between 6.4 and 8.6 at the conclusion of the experiment. The alkalinity and hardness values were not appreciably changed from that of the dilution water. The highest free CO_2 value obtained from any of the tests was 10 p.p.m., and most values were between 0.5 and 4 p.p.m.

Toxicity of Run-off from Dieldrin-treated Areas

The area selected for the dieldrin run-off studies was a grassy slope draining into a storm sewer at the west end of the Lawson General Hospital grounds. This plot contained 7.14 acres, of which 1.46 acres were covered by pavement and buildings. The remaining 5.68 acres of grassy slope were treated with the dieldrin formulation.

A weir and a continuous float-level recorder were installed at the storm sewer outfall to give an uninterrupted measure of run-off. A rain gauge was used to measure total rainfall and 15-minute intensity.

On January 22, 1954, before any treatment, a 60-gallon sample of run-off water was collected to determine if initial toxicity was present, and to obtain water for use as a diluent in bio-assays of run-off water and dieldrin formulations. On February 19, a dieldrin-attapulgus clay formulation was applied at the rate of 50 pounds per acre. The formulation used was a 40 to 60-mesh granular material containing 67.9 percent attapulgite clay, 21 percent hydrocarbon solvent, and 11.1 percent technical dieldrin. This

TABLE 1.—*Rainfall intensity and volume and amount of run-off from the dieldrin treated area.*

Rainfall				Runoff	
Period	Time and Date	Maximum 15-minute intensity inches	Total inches	Total 1000 gallons	Per cent of total rainfall
Prior to treatment	7:00 a.m. 1/21 to 1:00 p.m. 1/22	—	1.00	—	—
First rain after treatment	5:00 a.m. to 2:45 p.m. 2/20	0.120	0.86	37.9	13.7
Second rain after treatment	4:55 a.m. to 10:20 a.m. 2/24	0.015	0.135	None	None
Third rain after treatment	6:35 a.m. to 9:50 a.m. 2/28	0.075	0.605	7.3	3.5
Fourth rain after treatment	12:50 p.m. to 6:00 p.m. 2/28	0.08	0.61	30.1	15.0

TABLE 2.—*Physical and chemical characteristics of run-off from the dieldrin treated area.*

Period	Time collected	Turbidity p.p.m.	D.O. p.p.m.	pH	Total alkalinity p.p.m.	Free CO_2 p.p.m.	Hardness p.p.m.
Before treatment							
Peak	2:00 p.m.	25	8.4	6.8	40	8.0	—
First rain							
Start	2:20 p.m.	520	7.4	7.4	40	4.4	44
Peak	2:45 p.m.	155	7.6	6.7	20	6.2	24
Composite	2:20 to 4:20 p.m.	92	7.8	6.7	14	7.0	20
Third rain							
Start	7:25 a.m.	455	8.2	7.5	22	1.8	38
Peak	8:40 a.m.	140	8.4	7.1	14	1.8	26
Composite	7:15 to 10:15 a.m.	160	8.6	7.2	16	0.9	30
Fourth rain							
Start	2:30 p.m.	650	7.8	7.9	30	4.4	38
Peak	3:30 p.m.	105	7.8	7.1	18	2.6	20
Composite	2:30 to 7:00 p.m.	105	7.8	7.2	18	3.5	20

represented a dosage of 4.66 pounds of dieldrin per acre.

During each period of rainfall following the treatment, 10-gallon samples of run-off water were collected at the beginning of the run-off, at the peak, and a composite was collected of samples taken at 15-minute intervals throughout the run-off period. Samples were immediately shipped to the Sanitary Engineering Center for bio-assay.

The rainfall and run-off data before and after the dieldrin application is shown in Table 1. Four separate periods of rainfall occurred within a week after treatment. There was no run-off from the second rain. All of these rains were of moderate intensity and the maximum run-off produced was only 15 percent of the total rainfall.

Some of the physical and chemical characteristics of the run-off samples are shown in Table 2. Some samples were highly turbid, especially those taken at the start of run-off. The other characteristics would indicate a soft water quite low in dissolved solids content.

Bio-assays were made on all run-off samples using fathead minnows, *Pimephales promelas,* 2 to 2½ inches long and approximately 1.5 grams each in weight, as test fish. Run-off obtained before the dieldrin application was used for dilution water. Because of the limited amounts of run-off water available, bio-assays were carried out using four fish in six liters of each duplicate test concentration. The results of bio-assays with the run-off samples are shown in Table 3.

TABLE 3.—*Percent survival of fish and toxicity of run-off from the dieldrin treated area*

Runoff sample	Concentration tested (percent runoff)	Percent survival		TLm Percent concentration	
		24 hours	96 hours	24 hours	96 hours
First rain					
Start	100	37.5	0	—	—
	56	87.5	75	86	86
Peak	100	25	0	—	—
	56	50	50	—	—
	32	100	100	56	56
Composite	100	0	0	—	—
	56	37.5	25	—	—
	32	100	100	50	46
Third rain					
Start	100	75	50	—	100
Peak	100	75	62.5	—	—
Composite	100	87.5	87.5	—	—
Fourth rain					
Start	100	100	100	—	—
Peak	100	100	100	—	—
Composite	100	100	87.5	—	—
Control	100	100	100	—	—

Bio-assays of run-off from the first rain indicated that it was toxic to fathead minnows, with complete mortality occurring in less than 96 hours in all of the samples. Some deaths occurred in all samples of run-off from the third rain, but generally there was less than 50 percent mortality. Evidently run-off from the fourth rain contained some dieldrin, as a few of the fish exhibited characteristic reactions,[2] but not enough to be fatal. Only one fish of 24 succumbed in run-off samples from the fourth rain. No effect was observed in the control (run-off water prior to dieldrin application).

Estimation of the Dieldrin Content of Run-off Water

An effort was made to determine the quantity of dieldrin in run-off samples by bio-assays with fathead minnows. The dilution water used was the run-off obtained from the Lawson General Hospital grounds prior to applying dieldrin. A series of test concentrations was prepared by adding known amounts of the dieldrin-attapulgus clay formulation to the dilution waters. The concentrations, prepared in a logarithmic series of numbers, covered the range of 0.01 to 5 p.p.m. of dieldrin. Complete mixing was obtained by putting a concentrated stock solution into a Waring blendor for five minutes and diluting this concentrate to the desired test concentration. Fish were then added and their reactions observed continuously over a 96-hour period.

A summary of experimental data obtained by observing fish reactions in these prepared concentrations of dieldrin in run-off water is presented in Table 4. The times given are for complete loss of equilibrium and death, and were recorded only at 15-minute intervals. The 50 perecent values represent the effect on the fourth fish out of eight used in each concentration, while averages are the arithmetical average of the eight fish when the effect was complete. The 50 percent loss of equilibrium and death times were plotted against concentration on a log-log scale to obtain Figure 1.

Before obtaining the unknown run-off samples from the dieldrin-treated area, this curve was checked by preparing known concentrations of dieldrin and observing fish reactions. Within the range of 0.03 to 0.5 p.p.m. of dieldrin, it was found that the dieldrin content could be estimated within 25 percent of the amount present. Above these limits, the reaction time

[2]A characteristic physiological reaction was observed when fish were placed in water containing any form of dieldrin. All fishes tested exhibited a short initial period of high excitabilty followed by alternate perods of muscular spasms causing short jerky and violent movements (often fish would leap from the water almost to the top of the test container) and quiescent periods with partial loss of balance (the fish would remain suspended, sometimes in a vertical position). This was followed by complete loss of equilibrium and, after a time, death. The fathead minnows would swim on their backs with short jerky movements in a circular pattern around the edges of the test container for periods as long as twelve hours before death. A swelling of the abdominal region was also noted. These symptoms have not been observed with other toxicants used in this laboratory.

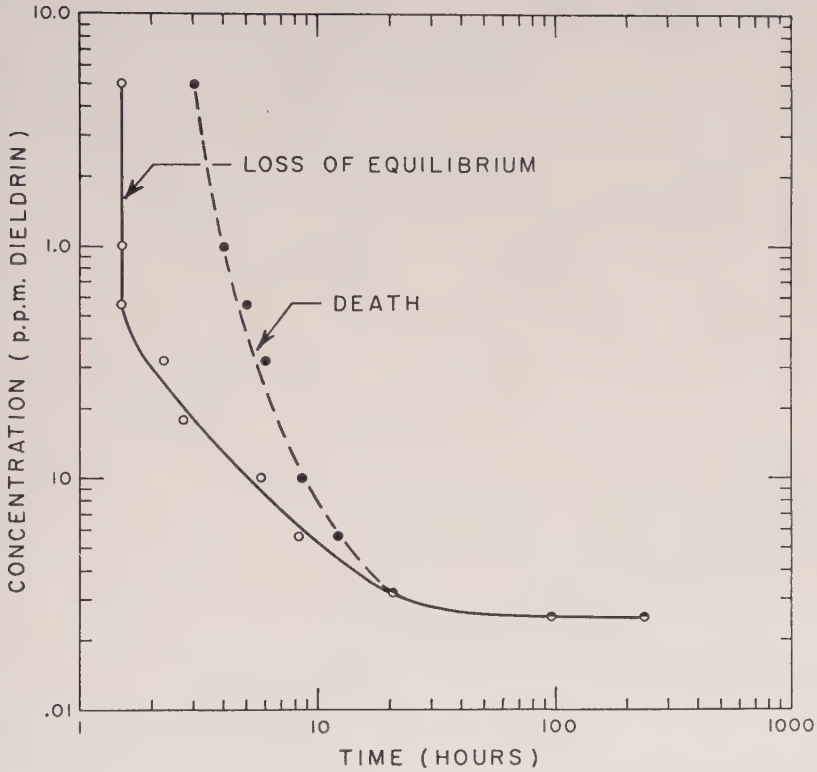

FIGURE 1.—Curve showing the time of loss of balance and kill of fish exposed to known concentrations of dieldrin.

was so similar that accurate estimates could not be made. It was also believed that within these limits more accurate estimates could be made using loss of balance as a criterion. However, at very high and low levels the death curve may prove to be more accurate. At high levels there was some slope to the death curve, while at low levels death occurred without prior loss of equilibrium. It seems that this method of estimating concentrations may be feasible. Use of a more sensitive fish as well as a statistical treatment of data may result in greater accuracy. In addition, physiological reactions may be used to indicate the type of material present.

The time-of-effect data and the estimated concentrations of dieldrin obtained by using the curve (Figure 1) is presented in Table 5. The 50 percent loss of balance and death times are used in these computations.

TABLE 4.—*Loss of balance and death times of fathead minows in known concentrations of dieldrin.*

Concentration p.p.m. dieldrin	Time in hours			
	Loss of equilibrium		Death	
	50 percent	Average	50 percent	Average
5.0	1½	1½	3	3¼
1.0	1½	1½	4	4¼
0.56	1½	1½	5	5¾
0.32	2¼	2¼	6	10
0.18	2¾	8¾	15	13½
0.10	5¾	6½	8½	9¾
0.056	8¼	11¾	12¼	16¼
0.032	20½	[1]	20½	[1]
0.018	—	[2]	—	[2]
0.010	—	[3]	—	[3]

[1]75 percent lost equilibrium and died in 96 hours.
[2]12 percent lost equilibrium and died in 96 hours.
[3]No loss of equilibrium or death in 96 hours.

TABLE 5.—*Estimates of concentrations of dieldrin in runoff from treated areas using the time-of-effect concentration curve.*

Sample	50 percent lost balance—hours	Estimated concentration p.p.m.	50 percent kill—hours	Estimated concentration p.p.m.
First rain				
Start	13	0.042	16	0.040
Peak	10	0.054	11	0.064
Composite	4	0.128	6	0.270
Third rain				
Start	94	0.025	94	0.025
Peak	—	—	[1]	0.018-0.025
Composite	—	—	[2]	0.018-0.025
Fourth rain				
Start	—	—	[3]	0.018
Peak	—	—	[3]	0.018
Composite	—	—	[4]	0.018

[1]62 percent survival
[2]75 percent survival
[3]100 percent survival
[4]87½ percent survival

An infrared spectrophotometric analysis of composites from the first and third rains gave reported quantities of dieldrin as 100 and 13 p.p.b. respectively, which were believed to be within 50 percent of the true concentration.

Based on the estimated quantities of dieldrin (Table 5) and the quantity of run-off (Table 1), only a very small portion of dieldrin applied could be accounted for. It is not known whether it was tied up in the soil, dissipated through a change in composition, or whether it remained to be washed into streams with further heavy rains.

Toxicity of Different Dieldrin Formulations to Some Common Species of Fish

A series of laboratory bio-assays were carried out using three dieldrin formulations and three species of fish under similar experimental conditions. A prepared soft water was used as the diluent.

The three dieldrin formulations used were: No. 1 the dieldrin-attapulgus clay suspension used in the run-off studies which contained 67.9 percent clay, 21 percent hydrocarbon solvent, and 11.1 percent technical dieldrin; No. 2 a dieldrin-xylene-triton emulsion containing 11.1 grams of technical dieldrin (10 grams pure dieldrin, 37.4 milliliters of xylene, and 1.5 milliliters of a triton emulsifier). This emulsion is similar to a commercial emulsible concentrate (Shell Chemical Corporation, 1953); No. 3—a dieldrin-acetone solution prepared by dissolving weighed quantities of recrystallized 99 percent pure dieldrin in measured quantities of acetone.

For formulations 1 and 2, stock preparations were made containing 0.01 and 0.1 percent dieldrin, which were then added directly to the dilution water in the test aquaria. Formulation 3 was added directly. The maximum amounts of hydrocarbon solvent, xylene, triton, or acetone added to any test solution was considerably less than that found to be toxic to fish.

The three different species of test fish were : fathead minnows, *Pimephales promelas,* 2 to 2½ inches long and weighing approximately 1.5 grams each; bluegill sunfish, *Lepomis macrochirus,* 2 to 2½ inches long and weighing approximately 2 grams; and green sunfish, *Lepomis cyanellus,* 2½ inches long and weighing approximately 2 grams.

It was evident that all formulations were extremely toxic to fish. The 96-hour TL_m values ranged from 0.0056 p.p.m. to 0.042 p.p.m., depending on the formulation and species of fish used. The average TL_m values of the three formulations in soft water and under uniform experimental conditions for the three species of fish are shown in Table 6. The variation from the average in separate experiments using the same formulation and dilution water was generally less than 10 percent.

From this comparison, it appears that the dieldrin-clay suspension is the least toxic (highest TL_m value) formulation to fathead minnows and

TABLE 6.—*Compartive toxicity of three dieldrin formulations to three species of fish under uniform experimental conditions.*

Species of fish	Number of experiments	Average TL_m values (p.p.m. dieldrin)		
		24 hours	48 hours	96 hours
Dieldrin-clay suspension				
Fathead minnows	2	0.050	0.039	0.036
Small bluegills	1	0.048	0.039	0.032
Green sunfish	1	0.018	0.0086	0.0062
Dieldrin-xylene-triton emulsion				
Fathead minnows	8	0.040	0.032	0.024
Small bluegills	1	0.035	0.018	0.018
Green sunfish	3	0.015	0.011	0.011
Dieldrin-acetone solution				
Fathead minnows	2	0.035	0.022	0.016
Small bluegills	1	0.013	0.0084	0.0079
Green sunfish	3	0.016	0.0095	0.0085

TABLE 7.—*Comparison of the toxicity of the dieldrin-clay suspension and dieldrin-xylene-triton emulsion in different dilution waters.*

Kind of water	Number of experiments	Average TL_m (p.p.m. dieldrin)		
		24 hours	48 hours	96 hours
Dieldrin-clay suspension				
Fathead minnows				
Prepared soft	2	0.050	0.039	0.036
Georgia run-off	1	0.032	0.025	0.025
Natural hard	3	0.034	0.026	0.023
Bluegill sunfish				
Prepared soft	1	0.048	0.039	0.032
Natural hard	1	0.042	0.038	0.022
Dieldrin-xylene-triton emulsion				
Fathead minnows				
Prepared soft	8	0.040	0.032	0.024
Natural hard	5	0.039	0.027	0.020

bluegills, the emulsion intermediate, and the acetone solution most toxic. All formulations were of approximately equal toxicity to green sunfish. Fathead minnows were the most resistant fish; they were followed by small bluegills and green sunfish. There was, however, little difference in the susceptibility of bluegills and green sunfish in the xylene emulsion and the acetone solution.

The fish tested exhibited a similar physiological reaction, as described previously, in all formulations. The period between complete loss of equilibrium and death in fathead minnows was much longer than that with either of the sunfishes. The swelling of the abdominal region was not as apparent in the sunfish as it was in the fathead minnow.

Effect of Different Dilution Waters on the Toxicity of Dieldrin

Because run-off from dieldrin-treated areas may enter many different types of water, and since the toxicity of many chemicals is dependent upon water quality characteristics such as pH, alkalinity, and hardness, an effort was made to determine if major differences occurred in dieldrin toxicity when using different waters for dilution.

Bio-assays were made using three different kinds of dilution water: (1) soft water prepared in the laboratory by mixing 95 parts of distilled water and 5 parts of a natural hard water; (2) Georgia run-off water—the water collected from the plot at Lawson General Hospital before treatment; and (3) hard water, a natural hard limestone water obtained directly from springs. The hard and soft waters encompass the pH, alkalinity, and hardness range of most natural waters. The characteristics of these dilution waters are given below.

	Turbidity p.p.m.	*pH*	*Alkalinity*	*Hardness*	*D.O.*
(1) Soft water	*less than* 5	7.4	18	20	8.4
(2) Georgia run-off water	25	7.1	38	40	7.8
(3) Hard water	*less than* 5	8.2	360	400	8.4

A direct comparison of the toxicity of dieldrin-clay suspension and dieldrin-xylene-triton emulsion in different dilution waters is shown in Table 7. While the range of toxicity in different dilution waters was not large, all experiments indicated that dieldrin was somewhat more toxic in hard water.

Effect of Increased Volume on the Toxicity of Dieldrin

To determine if exposing fish to larger volumes of the same concentration of dieldrin would allow for increased absorption of dieldrin and

thus greater toxicity, experiments were conducted using different ratios of fish to volume of water. Results of the study are shown in Table 8.

TABLE 8.—*Comparison of dieldrin toxicity when varying the ratio of fish to volume of test solutions.*

Number of fish	Volume of diluent	Ratio of fish per liter of water	TLm (p.p.m. dieldrin)		
			24 hours	48 hours	96 hours
8	12	1:1½	0.056	0.047	0.042
8	24	1:3	0.040	0.036	0.036
4	24	1:6	0.032	0.032	0.032

The toxicity appeared to be slightly increased with larger volumes of dilution water. However, this increase was small enough to be within the possible range of experimental error. Other experiments in which fish were added indicated no loss in toxicity due to absorption by the fish. Solutions allowed to stand for several days before adding fish proved as toxic as those to which fish were added immediately after preparation. This would indicate little toxicity loss through hydrolysis, precipitation, or chemical reaction.

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USE OF ARTIFICIAL AND NATURAL SPAWNING BEDS BY LAKE TROUT

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ABSTRACT

Artificial spawning beds for lake trout, made of sharp rocks, are better than natural spawning beds of round boulders. The eggs laid in the interstices between the sharp rocks are thereby protected to a certain extent against depredation by other fish, whereas, eggs laid on round boulders are easily reached by predators. SCUBA diving equipment was used to make observations of the spawning beds.

There has been divergence of opinion as to where *Salvelinus namaycush*, commonly known in the province of Quebec as the lake or grey trout or the touladi, spawns, and it has often been difficult to find the eggs after spawning. It has been claimed by some fisheries workers that lake trout spawn in deep water, at depths of 50 or even 100 feet, and by others that they spawn in very shallow waters around shores.

A series of observations in Quebec lakes supplies a partial answer to the question of spawning depth and also supplies information on the value of different spawning sites. In November, 1955, lake trout eggs were sought on spawning grounds in Lake Tremblant and Lake Superieur, both located in Terrebonne County of the Province of Quebec. With SCUBA equipment (self-contained underwater breathing apparatus) the author searched the bottom from shore to shore to a depth of approximately 20 feet. The bottom was of round boulders and gravel. An area of some 20,000 square feet was examined in the two lakes and no eggs were found lying on the bottom although many trout eggs were found in the stomachs of *Catostomus commersoni, Ameiurus nebulosus, Notemigonus crysoleucas* and *Perca flavescens* taken by nets in the area. This confirms reports in the literature, especially by Atkinson (1931) on predation of lake trout eggs by these species.

Another spawning bed was examined in Lake Massawippi in the Eastern Townships, and here, in contrast to the finding in Lake Tremblant and Lake Superieur, a large number of lake trout eggs were found between the rocks. Here perch were taken that had eaten many eggs, and were eating eggs, in waters so shallow that when they picked at the eggs their

tails were out of the water. Since eggs in such shallow water would be destroyed by freezing in winter, it would appear advantageous to raise the level of the water here about three feet before the winter season.

Why were there trout eggs on spawning beds in Lake Massawippi and not in Lakes Tremblant and Superieur? On comparing the conformation of the spawning grounds, it was noted that in Lake Massawippi the spawning grounds were of sharp angular rocks; quite a difference from the round boulders in lakes Tremblant and Superieur. The eggs in Massawippi were well protected by the sharp rocks; some were found as deep as one foot in interstices between the rocks. Here coarse fish could not easily reach and eat them.

The sharp rocks (Fig. 1) were not originally present but had been dumped on a sandy beach to seat a railroad track around the year 1900, and were piled here to a depth of 20 feet. It is unlikely that trout had spawned there before the addition of the rocks, since the underlying bottom is sand. It is not known how long the artificial spawning ground has been used but for the past 10 years the Quebec Department of Game

FIGURE 1.—Piled angular rocks for seating railroad forming an excellent spawning bed for lake trout in Lake Massawippi, Quebec.

FIGURE 2.—SCUBA diving equipment used for examining lake trout spawning beds in Quebec.

and Fisheries has been stripping lake trout for eggs here.

These observations suggest that artificial spawning grounds of sharp rocks are better than the natural spawning grounds of round boulders, and that it may be possible to improve existing spawning grounds in lakes, or create new spawning facilities, by adding sharp rocks.

The SCUBA equipment (Fig. 2) proved very useful for making observations of spawning beds in water as cold as 40°F.

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ALBERTA'S 'POTHOLE' TROUT FISHERIES

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ABSTRACT

Scattered across the prairies and foothills of Alberta lie a series of warm, shallow, rich lakes and reservoirs that vary in size from 15 to 100 acres. These "potholes" are distinguished from the larger lakes of the province by their lack of inlets and outlets. Some contain northern pike and yellow perch; others have small cyprinids only, or cyprinids and sticklebacks; one contains yellow perch and sticklebacks.

The potholes without northern pike, when stocked in the spring with fry or fingerlings of rainbow trout, provide fishing for 13- to 16-ounce fish by fall and for two to three pound fish by the second summer. From the first two stockings it is estimated that anglers recover roughly one-fifth of the total number and some sixty times the total weight of fish stocked. In the spring and fall the anglers catch about one fish per hour; during July to mid-September angling is poor and from 12 to 20 hours are required to catch one fish. This poor fishing is attributed to warm surface waters and low oxygen concentrations in deeper waters.

Trout fry or fingerlings stocked in third and subsequent years grow poorly and survive in small numbers. This is believed to be due to competition with the population established by the first two stockings. The management problems are discussed and it is concluded that poisoning the whole population every three or four years and beginning again is the best procedure.

The Alberta prairies and foothills are dotted with many small lakes that lack connection with river systems and maintain their levels by springs (a minority) or by surface drainage. The custom has arisen of calling these lakes "potholes." Also called "potholes" are a number of reservoirs created by damming coulees in the southern part of the province; water is stored in these for watering stock or for irrigation.

Potholes used for fish culture have areas from 15 to 100 acres. Mean depths are from six to eight feet and maximum depths from eight to fifty feet. Maximum depth of the majority is between 20 and 30 feet. Water of the few that have been analyzed contains 300 to 350 p.p.m. total solids.

Alkalinity ranges from 150 to 250 p.p.m. and consists of carbonates of lime and magnesium. Sulphates vary from traces to 50 p.p.m. The pH range from surface to bottom is 7.6 to 8.2; 7.6 is the commonest value. Maximum summer temperature, in July and August, is 68 to 77°F. Most of the lakes do not acquire a sharp thermal stratification.

The dissolved oxygen becomes low in the bottom waters during the summer. In winter, all the lakes show oxygen depletion of varying severity, depending on amount of snow cover on the ice and the time of the spring break-up. In the upper five feet of water, under the ice, the oxygen is frequently reduced to 3 p.p.m. in some winters but may not fall below 4.3 to 5.8 p.p.m. in others.

The lakes support very abundant plankton. Those on the prairies, particularly the reservoirs, produce heavy blooms of *Anabaena* and *Aphanizomenon* in July, August and September. In forested country and in the foothills, the blooms are less conspicuous, but a very rich crustacean fauna is present. On the whole, the bottom fauna is not rich. The annual oxygen depletion of the bottom waters leaves many with few midge larvae, amphipods and molluscs below the littoral zone. The littoral fauna is rich and consists of Hemiptera, Odonata, Trichoptera, Ephemerida, Amphipoda, Hirudinea and Gastropoda.

In the foothills the only fish resident in the lakes is the northern pearl dace *(Margariscus margarita nachtriebi* (Cox). In the southern reservoirs the fathhead minnow *(Pimephales promelas* Raf.) is abundant and the redbelly dace *(Chrosomus eos* Cope) occurs in a few. On the prairies some of the lakes contain perch *(Perca flavescens* (Mitchill) and most of them support the brook stickleback *(Eucalia inconstans* (Kirtland). Many of the potholes contain northern pike*(Esox lucius* L.) but in these no success has been achieved with trout.

Introduction of Rainbow Trout

The first stocking with rainbow trout in the pothole lakes was made in May, 1950. Three lakes in the foothills were planted with fry. Mitchell lake is typical. It has an area of 20 acres, maximum depth of 24 feet and a maximum summer temperature of 68°F. The resident fish is the pearl dace. Mitchell lake was stocked with 415 small fingerlings on May 20, 1950. By August 1951, that is, after two summers' growth, these fish had an average weight of two pounds. A second planting of 700 fingerlings was made in May, 1952 and a third, of 1,200, in June 1953. The lake was very heavily fished; no precise catch records are available, but the local Fish and Game Officer estimates that anglers caught 80 percent of the fish of the first planting, 50 percent of the second and none of the third. The fish of the first planting reached seven pounds in three summers. After five summers fish of 17 and 18 pounds were reported.

The history of the two other foothills lakes stocked in 1950 has been

the same. There has been a great initial success, with two years of good angling, and thereafter a rapid deterioration.

Good angling provided by these lakes encouraged trials in other lakes containing only cyprinids or perch. By 1955, 65 "potholes" were stocked. These included many reservoirs as well as warm-water lakes on the prairies. Some of the lakes were stocked with fingerlings, and others with yearling rainbow trout. With the staff available it has not been possible to follow the fate of the plantings in each body of water. Success or otherwise has been judged largely by unsolicited reports from anglers. However, in a few, an effort has been made to obtain accurate figures. This has been done by gill-netting and, on one lake, by maintaining a compulsory creel census for one season. As a typical example of the fate of the stocked trout and the kind of angling they provide, an account will be given of the history of Chickako Lake.

History of the Trout Fishery in Chickako Lake

Chickako Lake lies in rolling, wooded country. Formerly it was a part of a connected series of lakes but for many years it has been cut off from any drainage system. It has an area of 50 acres. The main basin is 35 feet deep with very gentle contours. A smaller basin, connected by a narrow strait, is steeper and has a maximum depth of 56 feet. The temperature reaches 72° to 75°F. in July and remains at that level until the first week in September. There is no sharp thermal stratification and the temperature falls evenly to 50° to 55.4°F. at 35 feet. Freeze-up occurs in November in most years and break-up of ice in late April or early May.

Dissolved oxygen remains close to saturation levels down to 15 feet during the summer. In the winter oxygen decline is noticeable in December and reaches a critical level in March and April. At this time there is no oxygen below 20 feet. Under the ice, dissolved oxygen falls as low as 4 p.p.m. (15 percent of saturation).

At one time the lake contained yellow perch but these winterkilled and, in 1953, when trout were introduced, only sticklebacks were present.

Plantings of rainbow trout were made as follows: first planting, May 1953, 5,300 fingerlings; second planting, May 1954, 2,852 yearlings and third planting, May 1955, 12,720 fingerlings.

Growth of Trout

Returns from angling and gill-netting have provided growth data for 1,324 trout. These data are summarized in Table 1.

Table 1 shows two noteworthy features about this growth record. One is the very rapid growth of the fish of the first plant. These reached three pounds after two summers in the lake and many individuals of six and seven pounds were caught at the end of the third summer. The second

TABLE 1.—*Summary of growth data for 1,324 rainbow trout from Chickako Lake, Alberta.*

Year Stocked	Average weight in ounces at end of summer: First Summer	Second Summer	Third Summer
1953	13.5	50	76
1954	10.0	35	—
1955	5.0	—	—

point of interest is the very pronounced decrease in growth rate of fish of the second and third plants.

These two aspects of the growth history are typical of all the stocked lakes. Evidently the fish first introduced flourish in the absence of competition; those of the later plants are forced to compete with survivors of the first plant and grow much more slowly.

SURVIVAL OF STOCKED TROUT

Unifortunately, it is not possible to get absolute survival figures. However, it is possible to assign the trout caught by angling and gill-netting to the correct planting. In Table 2 the total removals of trout from Chickako Lake are shown.

ANGLING SUCCESS

The creel census during the summer of 1955 was compulsory. A biologist camped at the lake and the catch of every fisherman was examined. Information was collected on the size and number of fish caught, hours of fishing, types of lure, depths fished and weather conditions. The time spent fishing and the catch are shown for each month in Table 3.

TABLE 2.—*Removals of planted trout from Chickako Lake, Alberta.*

	From 1953 plant	From 1954 plant	From 1955 plant
[1]Angling, 1953	200	—	—
[1]Angling, 1954	640	210	—
Gill-nets, January, 1955	110	43	—
[2]Angling, 1955	280	570	50
Gill-nets, October, 1955	5	35	0
Gill-nets, March, 1956	80	151	0
Totals	1315	1009	50

[1]Estimates from anglers' voluntary reports.
[2]Compulsory creel census.

The data in Table 3 show that fishing was good in May and October when approximately one trout was caught per hour of angling. The trout ranged in weight from two to five pounds. In June fishing was fair; on the average, three hours were required to catch a fish. In July, August and September fishing was extremely poor and it took 12 to 20 hours to catch one fish. These catch figures are clearly related to temperature and oxygen conditions. In the spring and fall, when fishing was good, the water was cool at the surface and well aerated. The trout were caught with trolled or cast surface lures such as flat-fish and flies. In summer the surface water became warm and the trout moved deep. Here the dissolved oxygen was low and the fish fed very little. The few successful anglers caught their fish by still-fishing with worms or minnows at depths of 20 feet or more.

The practicality of the stocking of Chickako Lake must be measured in terms of the harvest by anglers. The data required for this assessment are given in Table 4.

Angling return from the first stocking was 21 percent by numbers and over two hundred and thirty times by weight; of the second, 27 percent by numbers and nearly four times by weight. Recoveries from the third planting have so far been negligible.

General reports from anglers and our own observations indicate that this picture of angling applies to most of the potholes. There is one notable exception where angling continues at the one-trout-per-hour level all

TABLE 3.—*Rainbow trout catches in Chickado Lake, Alberta, during the summer of 1955.*

Month	Hours of Fishing	Catch/hour	Total Catch
[1]May	250	1.09	270
[1]June	500	0.31	155
July	959	0.05	52
August	1088	0.08	89
September	1000	0.07	70
[1]October	250	0.84	210

[1]In these three months the returns were provided by members of the Edmonton Trout Fishing Club who were cooperating in the study.

TABLE 4.—*Numbers and weights of trout planted and of trout caught by anglers in Chickako Lake, Alberta.*

Year of Planting	Number Stocked	Pounds Stocked	Number Caught	Pounds Caught
1953	5,300	15	1,120	3,500
1954	2,852	360	780	1,380
1955	12,720	40	50	negligible

year. This is a deep reservoir in a wind-swept area where summer oxygen depletion does not occur.

Effect of Resident Non-trout Fishes

The presence of sticklebacks and/or cyprinids before stocking with trout evidently does not interfere with the survival and growth of the trout. When the trout have been in the lakes three or four months they utilize some of these for food although their main food continues to be invertebrates. The presence of yellow perch did not prevent survival of the stocked trout, but it did interfere with their growth in Cottage Lake. This lake, which lies close to Chickako and is of a similar type, contains a large poupulation of stunted yellow perch. Rainbow trout were planted at the same times in the same years as in Chickako. The fish of the first planting at the end of the second summer reached an average weight of 36 ounces whereas, in Chickako, the weight attained was 50 ounces.

Returns from gill-netting suggest that the perch may have contributed to a smaller survival of the planted trout. In Chickako Lake a gill-net in January, 1955, took 110 of the first plant and 43 of the second; the same nets in Cottage Lake took 4 of the first plant and 17 of the second. A year later commercial fishermen, using gill-nets, were able to take 231 trout from Chickako and only 147 from Cottage Lake. The fish from Chickako Lake averaged three pounds and those from Cottage only two pounds.

The effect of resident northern pike on stocked trout is even more drastic. In 1953 Whitewood Lake, in the same area as Chickako and Cottage Lakes, contained a very small population of pike in their first year. Rainbow trout were planted in the springs of 1953, 1954 and 1955. The few trout that were recovered had an average weight of only 30 ounces after two summers' growth (36 in Cottage and 50 in Chickako). Commercial gill-net operations in March, 1956 took three trout and 284 northern pike. Two other lakes, one in the same area, with well-established pike populations received rainbow plantings. In these no survival of planted trout has been observed.

Management Problems

Management of pothole fisheries has two aspects: (1) stocking and (2) maintenance.

Stocking

Initial stocking of a pothole that contains only cyprinids or sticklebacks may be done with fingerlings or yearlings. Both methods have been used and it now appears that, as far as subsequent growth is concerned, fingerlings are preferable. In one lake fingerlings were planted in May of 1953,

and a year later, in May, 1954, the same lake was planted with the same hatchery stock, now yearlings. The fingerlings planted in 1953 weighed almost one pound each at the time of the second planting whereas their fellows from the rearing ponds weighed only 2 ounces. The 1953 plant continued to hold a pound or more advantage up to the time of writing (1956). In other lakes it has been possible to compare the growth of fingerlings stocked in one lake with that of yearlings stocked in another at the same time. After one year in the lakes the fingerlings were as large as the yearlings planted at the same time.

Another consideration is the number to be stocked, initially and in subsequent plants. The numbers chosen were 500 fingerlings per surface acre for the initial planting and 250 per surface acre for the second. For yearlings it was decided to plant 50 per surface acre. Lack of fish, road conditions, and shortage of tank trucks all combined to make adherence to this schedule impractical. The actual sizes of initial plants have varied from 7 to 500 per surface acre. Within this range no difference in growth rates has been observed. It is evident that an initial plant of 500 per surface acre is within the carrying capacity of the lakes. Regarding subsequent plants, the suppressing effect on their growth by the survivors of the first plants makes it impossible to draw conclusions about the effect of plants of different sizes. This introduces the second and most troublesome management problem.

Maintenance

It has been pointed out that all the potholes provide angling which the public regards as satisfactory for two or three years. Thereafter, angling rapidly deteriorates. Investigation of lakes with such deteriorated angling reveals a small population of very large trout (12 to 18 lbs.), and zero or very slight survival of any fish stocked during the third and subsequent years. The failure of the later plants to survive seems to be due to unsuccesful competition with the earlier plants. It is obvious that successful management requires removal of these older fish. This may be accomplished by angling, by gill-netting, by natural mortality and by poisoning.

Angling has not proved to be an efficient method for reducing the population. There have been no restrictions as to type of artificial lure or bait and the lakes have been open continuously to fishing. Angling pressure has been very heavy during the ice-free season and moderate during the winter, through the ice. In no pothole lake has angling prevented the ultimate deterioration of the fishery.

Gill-netting on a commercial scale was carried out on five of the potholes in the late winter of 1955-56. At this time the dissolved oxygen was reduced to traces in the deep water and 4 to 5 p.p.m. near the surface. It appears that the trout survive these very low oxygen concentrations by becoming very sluggish and dormant. Large rainbow trout normally strug-

gle violently when caught in gill-nets and pulled from the water. Those caught in the winter fishery were alive in the nets but they hung limply and did not struggle. It is likely that they were moving very little in the water so that the gill-nets failed to catch a significant proportion of them. It is doubtful if enough trout were removed to produce the desired effect. It is not practical to operate gill-nets on these small lakes during the summer when many anglers are present.

Natural mortalities have not been very helpful to management. It was hoped that winterkills would eliminate the trout from time to time. However, as pointed out above, the trout survive lower dissolved oxygen concentrations than was expected. Only the very shallow lakes, six to eight feet deep, have had extensive winterkills. In these the dissolved oxygen usually entirely disappears every winter and it is only rarely that trout survive to a second summer. Because of the small angling harvest during the first summer it is not practical to stock such lakes.

In the absence of winterkills the fish of the first planting remain in sufficient numbers to prevent survival of later plants for a period of six or seven years. There is some evidence that most of the six- and seven-year-old trout are males. The females ripen for the first time as two-year-olds. They resorb their eggs, probably because of no spawning facilities. After the trout have ripened a second time it is common to find their body cavities contain masses of hardened eggs. Possibly this leads to a higher mortality rate among the females. Unfortunately, precise figures on the changing sex ratio are not available but gill-net catches from one pothole were entirely of large male fish, five and six years old. Field officers reported a similar predominance of males among the large trout caught in two other potholes. If a way could be found of stocking only females the period of poor fishing might be substantially shortened.

Poisoning periodically is undoubtedly the best way of managing these lakes. Each lake should be poisoned every third or fourth year and a fresh start made. At the present time this practice is too costly.

Acknowledgments

We are indebted to Mr. H. B. Watkins, Superintendent of Fisheries for Alberta, whose interest in, and promotion of the pothole fisheries has made them possible.

THE CONTROL OF THE UPSTREAM MOVEMENT OF FISH WITH PULSATED DIRECT CURRENT[1]

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ABSTRACT

Alternating-current electromechanical devices installed in the mouths of streams have proved effective in stopping the spawning migrations of the parasitic sea lamprey *(Petromyzon marinus)* which has seriously damaged Great Lakes fisheries. In a few streams, excessive mortality has occurred to other fish at the alternating-current barriers. A direct-current unit was developed in an attempt to reduce this mortality. This direct-current "diversion device" consists of a row of suspended negative electrodes which begins at the end of a trap wing and extends across the river at a downstream angle of 45° and a series of pipes (positive electrodes) driven into the stream bank. A second array, consisting of horizontal pipes installed downstream and parallel to the suspended electrodes and connected to a series of rods driven into the bank near the positive electrodes, controls the electrical field and dissipates the collecting influence of the positive side of the circuit. The electrical field is established from the end of the trap wing to the opposite bank. Fish are diverted away from the negative electrodes and toward the bank near which the trap is located. The array is activiated by pulsated direct current of essentially square wave shape with pulses at a duty cycle of 0.66 and a repetition rate of 3 per second. Direct-current diversion devices were operated in conjunction with alternating-current barriers during 1956 in the Chocolay River, Marquette County, and the Silver River, Baraga County, Michigan.

A total of 15,814 fish comprising 21 species was handled at the Chocolay River with a mortality of 930, or 5.9 percent. If mortalities of fish moving downstream are disregarded, only 287, or 1.9 percent, of the fish moving upstream were killed in the Chocolay River.

In the Silver River, 78,648 fish comprising 21 species were taken from the trap of the direct-current diversion device. The total kill of fish moving upstream, including 289 sea lampreys, was 1,016, or 1.3 percent. This river had presented a serious problem in the operation of an alternating-current control device during previous seasons. In 1955, 85.5 percent of three important species of fish were killed at the control structure. During 1956, this mortality was reduced to 8.1 percent by the operation of the direct-current equipment.

INTRODUCTION

The development and application of control methods to reduce stocks of sea lampreys in the Great Lakes is one of the major objectives of the Great Lakes Fishery Investigations. Several methods of sea lamprey control

[1]This study was conducted under the direction of Leo F. Erkkila, Fishery Research Biologist, Marquette, Michigan.

have been tested. Among these, alternating-current electrical barriers combined with mechanical traps, installed near the mouths of streams and rivers, have proved the most effective in preventing sea lampreys from reaching spawning grounds (Applegate, Smith, and Nielsen, 1952). However, an efficient electrical control device not only must block or destroy sea lampreys, but also must inflict a minimum of damage on fish.

Excessive mortality of fish at electrical barriers has been encountered in a few streams (Erkkila, Smith, and McLain, 1956). Attempts to reduce this mortality have usually entailed modifications in the electrical fields and improvements to trapping facilities. The possibilites of using direct current in conjunction with, or as a substitute for, alternating current are being explored as an additional solution to this problem.

Preliminary work with direct current was done at the Fish and Wildlife Service's Hammond Bay Fishery Laboratory near Rogers City, Michigan (McLain and Nielsen, 1953). Laboratory tests proved that some fish could be made to swim to the positive electrode when subjected to the right type of current (see Applegate, Macy, and Harris, 1954, for literature pertaining to this principle). Preliminary field tests brought out some of the problems in the use of direct current as a leading or capturing device.

The present investigation began in the spring of 1955 with field tests in the Chocolay River, Marquette County, Michigan. Attempts were made to fish the full width of the river with a series of direct-current electrical feilds. These fields consisted of two leading, or guiding, fields and a diversionary field. The diversionary field, at negative potential, blocked an area in the center of the river. The leading fields were created from each end of the diversionary field to a trap, or combination of traps, installed near each bank. The positive electrodes were incorporated into the traps.

During periods of observation careful counts of all fish entering the electrical fields and their reactions were recorded. Only 3 percent of the fish penetrating the leading field failed to exhibit a good leading response and managed to leave the area. Thirty-eight percent were forced to enter a trap; 50 percent led to the entrance and were overcome, and 8 percent led to the sides of the trap. Fish failing to enter the trap and those leading to the sides (58 percent) were considered to represent potential mortality.

The two major factors which restricted the success were our inability to establish a uniform voltage gradient, and the failure to design a trap which would retain fish but allow compartively easy entrance. The lack of uniformity of the voltage gradient was by far the more important. Fish encountering voltages of the proper level midway between electrodes were confronted with a more intense field as the positive electrodes were approached. Many had difficulty negotiating the restricted opening of the

trap funnels because their movements were involuntary.

Observations of the reactions of fish to various components of the electrical fields led to the development of the device described here. By the time the present device was fully evolved in 1955, the movements of fish at the experimental site had nearly ceased; therefore, results were inconclusive but they indicated the desirability of further tests. This paper describes the device and the results obtained from experimental units operated in the Chocolay River and the Silver River, Baraga County, Michigan, during the 1956 season.

The common and scientific names of the species of fish mentioned in this report are as follows:

Sea lamprey	*Petromyzon marinus*
Silver lamprey	*Ichthyomyzon unicuspis*
Rainbow trout	*Salmo gairdneri*
Brown trout	*Salmo trutta*
Brook trout	*Salvelinus fontinalis*
Smelt	*Osmerus mordax*
White sucker	*Catostomus commersoni*
Longnose sucker	*Catostomus catostomus*
Silver redhorse	*Moxostoma anisurum*
Golden shiner	*Notemigonus crysoleucas*
Creek chub	*Semotilus atromaculatus*
Pearl dace	*Semotilus margarita nachtriebi*
Common shiner	*Notropis cornutus*
Longnose dace	*Rhinichthys cataractae*
Brown bullhead	*Ictalurus nebulosus*
Northern pike	*Esox lucius*
Burbot	*Lota lota*
Trout-perch	*Percopsis omiscomaycus*
Ninespine stickleback	*Pungitius pungitius*
Yellow perch	*Perca flavescens*
Logperch	*Percina caprodes*
Smallmouth bass	*Micropterus dolomieu*
Pumpkinseed	*Lepomis gibbosus*
Rock bass	*Ambloplites rupestris*
Freshwater sculpins	*Cottus bairdi* and *cognatus*

The Direct-current Diversion Device

The device is based on the principle that a unidirectional movement of fish is induced by pulsated direct-current electricity. The movement is toward the positive electrode, or away from the negative electrode. Since prolonged proximity to the positive electrode results in undesirable electrical narcotization of fishes, the device is designed to establish in the water only the negative half of a guiding field and thus to eliminate any collecting or narcotizing influence of a positive electrode. The device acts therefore as a diversionary unit.

The equipment is a "grounded system" in which the negative side of the circuit is placed in the water while the positive side is grounded to electrodes driven into the stream bank. The first model as installed in

the Chocolay River consisted of:

1. A trap (4 by 4 by 6 feet, covered with ½-inch-mesh hardware cloth) placed against the west bank of the stream—a 10-foot wing, also covered with hardware cloth, extended downstream from the trap at an angle of 45°;
2. A suspended row of ½-inch galvanized-pipe electrodes spaced 6 inches apart, beginning 20 inches from the end of the wing and running completely across the river at the same angle (negative electrode array);
3. A row of copperweld ground rods, 6 to 8 feet long and spaced 6 feet apart driven into the west bank of the stream in a line parallel to the shore about 8 feet from the water's edge and two ground rods placed in the bank near the trap (positive electrodes);
4. A submerged horizontal pipe, 1½ inches in diameter, suspended at mid-depth or placed on the bottom of the stream 5 feet downstream from and parallel with the suspended electrodes—the pipe was connected at intervals to ground rods driven into the stream bottom and to a row of ground rods in the west bank 4 feet streamward of and parallel to the original row (in further discussion this unit is termed the "control array"); and
5. A power supply to furnish pulsated direct current. The negative side of the power supply[2] is attached to the row of suspended electrodes and the positive side is connected to the row of ground rods farthest from the stream bank. The power unit produced pulses at a duty cycle of 0.66, a repetition rate of three pulses per second, and an essentially square wave shape. Although other investigators (Groody, Loukashkin, and Grant, 1952: Haskel, MacDougal, and Geduldig, 1954; Houston, 1949; Raymond, 1956; and Trefethen, 1955) have reported various pulse durations, repetition rates, and wave shapes, response by the species of fish involved in the present study has been satisfactory with the type of current described above.

The control array (see item 4 above) served two functions: it extended the electrical field at a higher intensity for a desired distance from the negative electrodes, and it eliminated or greatly reduced the electrical field near the west bank and the entrance of the trap. Without the control array a strong field existed near the cathodes but 1 foot distant from them only 0.18 volt per inch was measureable, when 110 volts were applied to the array. The control array increased the voltage gradient to 0.35 volt per inch 1 foot from the cathodes, even when the applied voltage was reduced to 100 volts. At 4 feet from the electrodes the gradient at median water depth was twice that which existed without the control array (Figure 1). Alhough the characteristics of the electrical field were considered satisfactory with the horizontal control array pipe on the stream bottom, even

[2]The electrical equipment is basically the same as described by McLain and Nielsen (1953).

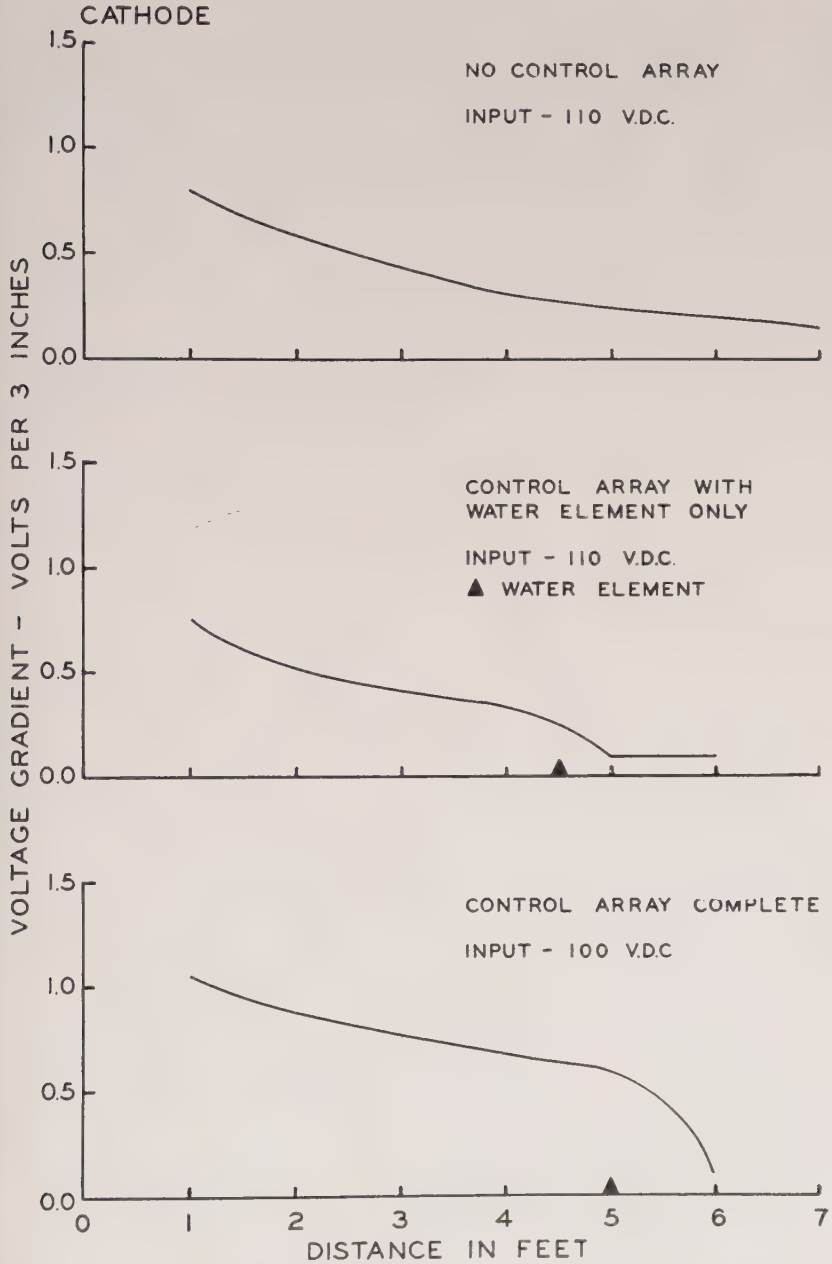

FIGURE 1.—Voltage gradients in volts per 3 inches as influenced by the control array of the direct-current diversion device.

better performance was obtained when the pipe was placed at mid-depth. A 1½-inch pipe provided sufficient surface for the horizontal element of the array in water depths up to 4 feet when suspended at mid-depth. In the two experimental units operated in 1956, two rows of 1¼-inch pipe were used. One row was laid on the bottom and the other was mounted approximately 18 inches above the first. They were held in place by 8-foot steel fence posts driven into the bottom.

The correct spacing between various components of the array cannot be precisely predetermined. The array functions as a "voltage divider" so that a portion of the drop in the applied voltage occurs between the negative electrodes and the horizontal pipe of the control array and a portion between the units on the bank. The extent of voltage drop between each depends on the total applied voltage and the resistance of the water and the soil. For satisfactory operation it is important that the spacing between the rows of ground rods in the bank produce a voltage drop great enough to eliminate any collecting influence at the horizontal pipe downstream from the hanging electrodes, and that the spacing between the horizontal pipe and the hanging electrodes be sufficient to develop a field that controls fish moving into it. On the Chocolay River in 1956, the horizontal pipe was placed originally 5 feet from the negative electrodes and later was moved to 6 feet. At the Silver River installation the spacing between the two originally was 5 feet and later was reduced to 4 feet.

The negative electrodes must provide a large amount of surface area to assure an even distribution of lines of force throughout the electrical field. As described in item 2, the original device had ½-inch pipes hung 6 inches apart. The two experimental models operated during 1956 used 1¼-inch pipes spaced 1 foot apart.

Requirements on placement and spacing are less exacting for positive than for negative electrodes. The number of electrodes used, or the amount of surface area required, in the positive array depends on the soil conditions. The unit as operated on the Chocolay River during 1956 had eight positive electrodes, ½-inch in diameter, and approximately 7 feet long. These were driven 2 feet apart in a line parallel to and about 8 feet from the water's edge. The Silver River device required 10 pieces of 1¼-inch pipe driven 10 feet to overcome the high resistance of the soil. As with the Chocolay unit, they were spaced about 2 feet apart and located about 8 feet from the water's edge.

As stated previously, the distance between each positive electrode and its corresponding bank electrode of the control array depends upon the soil resistance and that portion of the total voltage drop it is necessary to make in the bank to eliminate a collecting influence at the horizontal pipes of the control array in the water. The minimum allowable voltage drop in the bank is unknown. The original device dropped nearly 70 percent of the applied voltage in the bank with the spacing as described in item 4. The spacing between the positive electrodes and the bank elements

of the control array of the two devices operated during 1956 was reduced to about 2 inches. This change reduced the voltage drop to 50 percent or less of the total applied voltage. The reduced spacing resulted in an increase in the percentage of voltage available to the water. It also reduced the resistance and allowed more amperes of current. Since the desired galvanotaxic response of a fish is not a factor of voltage or of amperage but of energy (Cattley, 1955), it was necessary to reduce the applied voltage. The modified device was not more efficient from the standpoint of power consumption as the increased amperage compensated the reduction of voltage and power consumption in terms of watts remained comparatively stable.

A minor but important component of the device not heretofore discussed is a "wing control" to regulate the electrical field between the end of the trap wing and the first negative electrode. Inasmuch as the metallic end of the wing is closer to the first negative electrode than to the horizontal pipes of the control array, a large concentration of lines of force exists at this point; the direction of flow is toward the end of the wing. Fish which enter this area are diverted toward the wing. Some of the fish move to the upstream side of the wing where they either manage to escape upstream or are held against the surface of the wing by the electrical stimulus. The wing control supplies a metal surface which attracts part of the electrical current moving to the wing and changes its direction to assure that the fish are diverted to the downstream side of the wing.

Two types of "wing control" have been installed. The first consists of bare copper wire attached to the end of the wing. The 1956 Chocolay structure had ¼-inch copper tubing. The wire extended to a point halfway between the first negative electrode and the end of the horizontal pipe of the control array.

In the second type, used in the Silver River, three lengths of 1¼-inch pipe were driven along the line followed by the wire. The first pipe was about 6 inches from the wing and the succeeding pipes were spaced approximately 1 foot apart. The pipes were long enough to be driven securely into the bottom of the river and extend above the surface of the water. They were connected electrically to each other and to a fourth pipe driven about 3 inches from one of the positive electrodes. This arrangement functioned exactly as the control array. Both methods of controlling the electrical field at the end of the wing were successful.

The complete device is illustrated diagrammatically in Figure 2. The electrical field is established from the end of the trap wing to the opposite bank of the river. The inside of the trap and the area between the trap wing and the bank are free of any electrical current. The device simply turns back or diverts fish from the suspended negative electrodes to the bank along which the trap is located. The fish are free to enter the trap or return downstream.

Inasmuch as the electrical energy necessary to control sea lamprey move-

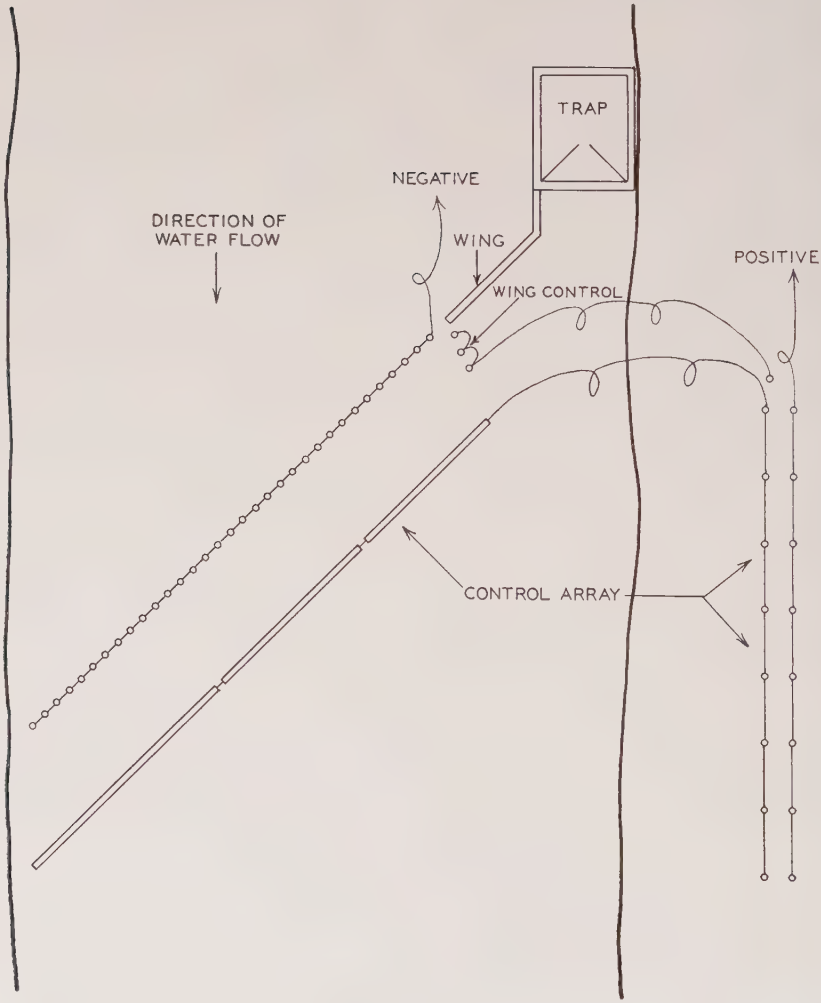

FIGURE 2.—A diagrammatic sketch of the trap and electrode arrays of the direct-current diversion device.

ments is greater than that required to control movements of fish, alternating-current control structures were installed immediately above the direct-current diversion devices.

Power Requirements of the Direct-current Diversion Device

The operation of many alternating-current control devices had indicated that each river has its own characteristics which greatly influence the efficiency of an electrical barrier, (Erkkila, Smith, and McLain, 1956). What changes in power demands or modifications to the electrode array of a direct-current diversion device would be necessary in other rivers is unknown. However, the structures as operated in the Chocolay and Silver Rivers functioned at nearly the same power levels.

Inasmuch as voltage, voltage gradient, or amperage, considered individually, are undependable as criteria of the efficiency of an electrical field, energy expressed in watts was used as the basis for establishing the intensity of the electrical fields.

Fortunately the design of the device is such that it functions satisfactorily over a fair range of power applied to the water. Since power in watts is the product of the voltage and amperage, power remains constant only while they remain constant or undergo compensating changes. Neither voltage nor amperage can be controlled exactly in the equipment. Amperage is dependent on the input voltage and the total resistance in the circuit. The resistance between the electrode arrays of the direct-current structures is not constant due to almost continual fluctuations of water conductivity, water level which regulates immersed electrode surface area, and, to a much lesser degree, fluctuations of soil conductivity with changes in moisture content. A change in the resistance of either the water or soil alters the amperage and also causes the voltage drop in the water to change relative to that in the bank.

Although 400 watts applied to the water was considered desirable, the devices functioned satisfactorily over a range of 300 to 500 watts. The voltage input ranged from about 120 to 200 volts direct current at 4 to 6 amperes. The voltage and amperage varied in a relationship that resulted in a total power consumption (including losses in transformers, rectifiers, . . .) of about 900 watts for each device.

Experimental Sites

The Chocolay River is 50 feet wide and well contained between its banks except for periods of extreme flood. Maximum depth is 2 feet during low-water stages and approximately 6 feet at flood stage. The bottom is predominately soft, shifting sand overlying clay. Water velocities varied from 1.5 to 2.5 feet per second. From early spring until mid-summer, the water

conductivity ranged from 63.78 to 136. 50 micromhos at 18°C.[3]

The Silver River is 70 feet wide and about 3 feet deep during low-water periods. Its bottom is also soft, shifting sand. During flood periods, water velocities of 2 feet per second were measured. Velocity drops to 0.5 foot per second and during late May, June, and July almost constantly recurring periods of reversing flow occur because of seiche in Lake Superior. The maximum rises in water level and upstream velocity due to seiche action during the 1956 season were 0.95 foot and an estimated 2 feet per second, respectively. Lake seiche and low water velocities were major factors contributing to the inefficiency of the alternating-current control device operated on the Silver River during preceding seasons. Water conductivity varied during the period of operation from 30.70 to 104.82 micromhos at 18°C.

Experimental Procedure

The direct-current diversion device was designed to operate downstream from, but in conjunction with, an alternating-current barrier. Therefore it was necessary to distinguish between fish moving downstream through the alternating-current electrical field and those moving upstream from the lakes if an adequate evaluation of the direct-current installation was to be made. The timing of upstream migrations of fish into Lake Superior streams has been well established by weir operations over the past 6 years. Consequently, the experimental direct-current devices were installed before any migration started except that of rainbow trout. Few fish except rainbow trout could be expected to move downstream until some had been passed upstream through the traps. All large fish released upstream from the trap at the direct-current device were marked by removing a portion of the right pectoral fin so that they could be identified if taken or killed on their downstream migration through the alternating-current field. The traps were emptied daily by a service crew which also marked fish and searched the stream in the vicinity of the barriers for dead fish. During the periods of heavy fish movement, the Chocolay River was patrolled for 1 mile downstream from the control site and the Silver River was covered from the control site downstream to its mouth, approximately ¾ mile. Recoveries of dead fish were recorded by species, fin mark, and location (*i.e.* alternating-current field, direct-current field, or downstream).

Water temperature, water level, and electric power consumption were recorded daily. Water conductivity was measured almost daily and water samples were collected for analysis of electrolytic content. Water velocities were checked with each appreciable change in volume of flow.

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[3]Water conductivity measurements were taken with a conductivity bridge, Industrial Instruments, Inc., Model RC-16B-1. The formula used to correct conductivity readings to 18°C. is as follows:

$$C_{18} = \frac{1{,}000{,}000}{Rt \times [1 + (0.02 \triangle t)]}$$

Where C_{18} equals calculated conducitivity at 18°C. in reciprocal megohms; Rt equals resistance of water at temperature t; $\triangle t$ equals $t - 18$; and t equals temperature at which the measurement was made.

TABLE 1.—*Records of fish taken in the trap of the direct-current diversion device and fish killed at the Chocolay River sea lamprey control site during the 1956 season*

[The table does not include mortalities of fish marked and passed upstream. Neither does it include adjustment covering periods of malfunction of the direct-current unit]

Species	Total number of fish handled	Number of fish trapped	Number of fish killed				Percentage kill of total handled
			A.C. field	D.C. field	Downstream	Total	
Sea lamprey	6,502	6,054	395	46	7	448	6.9
Longnose sucker	5,217	4,980	40	67	130	237	4.5
White sucker[1]	1,141	1,113	18	3	7	28	2.5
White sucker[2]	733	730	3	..	..	3	0.4
Rainbow trout[3]	114	108	1	2	3	6	5.3
Rainbow trout[4]	434	239	193	2	..	195	44.9
Smelt	713	713					..
Pumpkinseed	402	402		..	..		..
Brown bullhead	182	182	..	..	..	..	..
Creek chub	178	174	3	1	..	4	2.3
Miscellaneous[5]	198	189	8	1	..	9	4.5
Totals	15,814	14,884	661	122	147	930	5.9

[1]Spawning migrants over 9 inches, total length.
[2]Under 9 inches, total length.
[3]Spawning migrants over 12 inches, total length.
[4]Immature rainbow trout which represent a downstream movement. This accounts for the large number killed in the alternating-current field.
[5]Miscellaneous includes: brook trout, brown trout, burbot, longnose dace, northern pearl dace, freshwater sculpin, ninespine stickleback, yellow perch, and rock bass.

OPERATION OF DIVERSION DEVICES

Th Chocolay River device was operated from April 13 to July 25 and the one in the Silver River from April 20 to June 30, 1956.

CHOCOLAY RIVER

A total of 15,814 fish comprising 21 species were handled at the Chocolay River. The mortality was 930 fish, or 5.9 percent (Table 1). In addition, 220 of the marked fish released upstream from the traps of the direct-current structure were killed. The marked fish were subjected to the alternating-current field on their return downstream. Included in the 930 individuals killed were 195 small rainbow trout, of which 193 were found in the alternating-current field. They were killed as they moved downstream. An area near the bank which had very low water velocities accounted for a large portion of the young rainbow trout killed.

The kill also includes 448 sea lampreys of which 395, or 82.2 percent, were found dead in the alternating-current field. The direct-current voltages were not adjusted to control sea lampreys. However, 93.1 percent of all the sea lampreys moving up the Chocolay River were trapped by the direct-current unit.

Contributing to the mortality were 13 intervals of time during which the direct-current device was inoperative or functioning unsatisfactorily. It was impossible to determine accurately the mortality attributable to the malfunctions of the direct-current unit. Disregarding periods of malfunction, but eliminating mortalities of downbound fish and of sea lampreys, the total kill of fish moving upstream was only 287 or 1.9 percent of the total.

Of the total number killed, including marked fish, 69 percent were found in the alternating-current field. Of the remaining 356 fish, the number killed by exposure to the alternating-current field is unknown. It can be assumed that some of those found dead in the direct-current field had floated down from the alternating-current field.

Silver River

In the Silver River, 78,648 fish comprising 21 species were taken from the trap of the direct-current diversion unit (Table 2). The kill of fish at and below the control site totaled 1,228, including 289 sea lampreys and 212 marked fish. Runs of smelt and trout-perch into Silver River were much larger than those in the Chocolay River. The direct-current diversion

Table 2.—*Records of fish taken in the trap of the direct-current diversion device and fish killed at the Silver River sea lamprey control site during the 1956 season*

[The table does not include mortalities of fish marked and passed upstream. Neither does it include adjustment covering periods of malfunction of the direct-current unit]

Species	Total number of fish handled	Number of fish trapped	Number of fish killed				Percentage kill of total handled
			A.C. field	D.C. field	Downstream	Total	
Sea lamprey	857	568	150	138	1	289	33.7
Longnose sucker	74	70	..	4	..	4	5.4
White sucker[1]	4,205	4,057	69	61	18	148	3.5
White sucker[2]	271	270	1	..	..	1	0.4
Rainbow trout[3]	50	45	3	2	..	5	10.0
Rainbow trout[4]	69	62	5	2	..	7	10.1
Smelt	51,774	51,417	357	..	..	357	0.7
Trout-perch	20,073	19,898	175	..	..	175	0.9
Logperch	1,705	1,680	25	..	..	25	1.5
Common shiner	182	182	..	..	..	..	..
Creek chub	158	158	..	..	..	..	..
Miscellaneous[5]	246	241	5	..	..	5	2.0
Totals	79,664	78,648	790	207	19	1,016	1.3

[1]Spawning migrants over 9 inches, total length.
[2]Under 9 inches, total length.
[3]Spawning migrants over 12 inches, total length.
[4]Under 12 inches, total length.
[5]Miscellaneous includes: brook trout, silver redhorse sucker, smallmouth bass, yellow perch, rock bass, brown bullhead, burbot, longnose dace, golden shiner, freshwater sculpin, and silver lamprey.

device handled the very large smelt run excellently. Mortality due to electrical shock was insignificant in relation to the large number of fish. Only 357 smelt were killed while 51,417 were trapped. More smelt would have been taken but the catch was limited by the capacity of the trap.

Mortality to trout-perch was also very low—175 dead while 19,898 were caught in the trap.

Disregarding marked fish that were killed while moving downstream, 1,016 (1.3 percent) of the total number of fish handled were killed. Contributing to this mortality were seven periods of time during which the direct-current unit was inoperative or functioning improperly. Usually it was impossible to determine accurately the mortality attributable to equipment faiure. However, three of the seven periods of malfunction are believed to be directly responsible for the deaths of two of the five rainbow trout and 69 of the 148 white suckers.

During the operation of an alternating-current barrier on the Silver River in 1955, mortalities were: large rainbow trout, 90.0 percent; longnose suckers, 72.1 percent; and white suckers 85.5 percent. The 1955 mortality records do not indicate the direction of movement of the fish at time of death. In 1956, when the direct-current diversion device was in operation, the mortality from all sources was: large rainbow trout, 15.1 percent; longnose suckers, 10.3 percent; and white suckers, 8.0 percent (Table 3). If it is assumed that all other factors were equal in the two seasons of operation, the mortality of the three species in the Silver River was reduced from 85.5 to 8.1 percent by the diversion unit.

Factors of Mortality in the Operation of the Direct-current Units

The operation of the direct-current units drastically reduced, but did not eliminate, mortality of fish ascending the Chocolay and Silver Rivers. Some of the factors which contributed to the kill of fish were determined

Table 3.—*Comparison of fish mortalities in the Silver River during the 1955 season with the operation of a standard alternating-current barrier and the 1956 season with the experimental direction-current diversion device operated in conjunction with the alternating-current control*

Species	1955			1956		
	Number trapped	Number killed	Percentage killed	Number trapped	Number killed[1]	Percentage killed
Longnose sucker	38	98	72.1	70	8	10.3
White sucker	469	2,877	86.0	4,057	353	8.0
Rainbow trout	3	27	90.0	45	8	15.1

[1]The 1956 kill includes marked fish (fish moving back downstream). For the 1955 data it can be assumed that a few of those fish trapped and released upstream contributed to the mortality on their return. It is obvious from the figures that their contribution was not great.

and rectified, but others persist. A brief review of certain of the problems is given in the following paragraphs.

Equipment Breakdown

A mechanical firing apparatus was used at both installations to provide the pulsated direct current. The weaknesses of this apparatus were known but satisfactory service was expected from specially designed heavy-duty contactors. However, their failure was the major cause of breakdown. An electronic firing device was acquired and placed in operation at the Chocolay River. It functioned for a period of 85 days without an interruption. Equipment of this type should greatly reduce breakdown problems at future installations.

Malfunction Due to Improper Installation

A portion of the mortality can be attributed to improper installation. One example was the positioning of the lowermost pipe of the control array. To keep the pipe from covering with sand, it was suspended just off the bottom. A number of suckers, when swimming involuntarily out of the rather intense negative field, attempted to swim under this pipe and were wedged between the pipe and the bottom.

The attempt to eliminate this problem in the Chocolay River led to still further difficulty. The pipe was raised to provide sufficient space for fish to pass beneath it. This change was followed by a drop in stream flow which exposed 40 feet of the control array on the shallow east side of the river. The result was an intense and narrow field in close proximity to the negative electrodes opposite the exposed section of the control array. Seventy-nine longnose suckers, the largest number killed in any like period in the Chocolay River, were killed during that time. When the pipe of the control array was lowered to the bottom of the river results again were satisfactory.

Applied Voltages

The limited experience gained during the latter part of the 1955 season was insufficient to provide standards for operations at the start of the 1956 season. Proper operating voltages had to be determined. Applied voltages were set high at the beginning of the season and then were decreased gradually until suckers were able to penetrate the direct-current field. Voltage was then adjusted upward to a proper level. Although mortality was low during this phase of the experiment, the few fish killed contributed to total mortality.

Other Factors of Mortality

Flood stages in both rivers contributed to the kill. The water rose over the trap and trap leads allowing fish to bypass the direct-current field and enter the alternating-current field upstream where some were killed.

A few suckers and two of the rainbow trout killed in the direct-current field in the Silver River were stranded on the bank opposite the trap. It appeared that the fish entered the field almost parallel to it and turned to their left when stimulated by the guiding field. The line of suspended electrodes was placed at a 45° angle to cause fish moving upstream to turn to their right toward the bank where the trap was located. The stranded fish apparently entered the field so close to the bank that there was not room to change direction. Since their movements were involuntary and they could not avoid obstacles, they swam into the bank. One rainbow trout drove into the mud beyond its gill covers, and another was tightly wedged between roots. A continued exposure to the electrical field resulted in death.

Inability to handle the immense numbers of fish during heavy runs most probably caused mortality, but the extent could not be estimated. At the height of the smelt run in the Silver River, the trap filled immediately after it was emptied while unknown thousands continued their attempts to enter the trap. A comparable situation existed on both rivers during periods of heavy movement of suckers. The traps were rapidly filled to capacity, leaving a large number of suckers below the barrier still subjected to the electrical field.

Other factors not heretofore discussed which may have some bearing on mortalities are: variations in reaction of fish of different size to the same voltage—the device attempted to control at one power level the movement of fish as small as trout-perch, 3 to 4 inches long and as large as rainbow trout which occasionally reached 30 inches or more; temperatures—the device was operated throughout the entire temperature range experienced in those streams (temperature not only affects the reaction of some species of fish to an electrical stimulus but greatly influences electrical conductivity of the water); variation of response—fish of the same length in a given species may respond differently to the same amount of electrical energy (McLain[4]); changes in behavior of fish with changes in water load and stream velocity.

Conclusion

In view of the complexity of the situation—numerous kinds and sizes of fish and the many factors affecting operational efficiency, the results obtained exceeded those anticipated. In any application where the purpose

[4]McLain, Alberton L. 1953. Reaction of walleyes (Stizostedion v. vitrtum) to direct current. Typewritten report, 11 pp. U. S. Fish and Wildlife Service, Ann Arbor, Michigan.

is to divert the upstream movement of fish the direct-current diversion device should be highly satisfactory. At its present stage of development, the equipment cannot be used as a sea lamprey control unit without an alternating-current unit upstream from it because of the possibility of escapement of sea lampreys. It does provide an effective means of protecting and handling migrations of useful fish occurring at the same time as the sea lamprey runs.

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NORTHERN PIKE YEAR-CLASS STRENGTH AND SPRING WATER LEVELS

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ABSTRACT

Relationships between spring water levels and strength of year classes of northern pike *(Esox lucius)* produced in Ball Club Lake of north-central Minnesota are considered for the 7 years between 1945 and 1952. The years are ranked according to water conditions, including height during spawning and fluctuation during egg incubation, and according to the strength of year classes produced as judged from their abundance in the darkhouse spearing catch. Comparison of these two rankings by a rank difference correlation shows a correlation of 0.61. It is concluded that a high spring water level during spawning and a small decline in the levels during egg incubation represent good conditions for the production of a strong northern pike year class.

INTRODUCTION

The northern pike is an important sport fish in Minnesota. Pike are taken both by summer angling and winter darkhouse spearing. Understanding of environmental factors that influence abundance is essential for pike management, and indirectly, for management of associated fishes; especially yellow perch *(Perca flavescens)* and yellow walleye *(Stizostedion vitreum)*. In Minnesota northern pike occur throughout the state but are most abundant in lakes larger than 300 acres which have moderate to high chemical fertility, extensive littoral area, and adjacent or connected flowage or marsh area. In these flowages and marshes the pike spawn in early spring, usually between March 15 and May 1.

It has long been observed in Minnesota and elsewhere that high water levels in spring and flooding of grassy sloughs are often associated with good northern pike reproduction. Carbine (1944) at Houghton Lake, Michigan, attributed the highest survival of northern pike eggs and young in 1942 as compared to 1939 and 1940 to higher and more constant water levels in 1942.

The present study on the relationship between water levels and reproductive success of northern pike was made at Ball Club Lake in Itasca County of north-central Minnesota. This lake has a length of 5 miles, a width of 1.5 miles, and an area of 5,111 acres. The shoreline is quite regular. The

southern third of the lake has much shallow water, 60 percent being less than 20 feet deep. The northern two-thirds is deeper and here 30 percent of the area is shallower than 20 feet. The water is clear and free from from noticeable algal blooms and is hard (total alkalinity 138 p.p.m.). Marshy areas in restricted portions of the lake, and extensive adjacent and connected flowages provide excellent spawning grounds for northern pike. These spawning areas are flooded during high water stages in spring but may be dry in late summer.

Test netting with experimental gillnets that are 250 feet in length and have five mesh sizes ranging from 0.75 to 2.0 inches bar-measure and with trapnets of 1inch bar-measure and with 50-foot leads was done during the summers of 1952 and 1954. This netting showed a game-fish population primarily of northern pike and yellow walleye. Black crappies, *Pomoxis nigro-maculatus* were present in small numbers. Other components of the fish population were: yellow perch; tullibee or shallow-water cisco, *Leucichthys (Coregonus) artedi;* white sucker, *Catostomus commersoni;* lake whitefish, *Coregonus clupeaformis:* brown bullhead, *Ictalurus nebulosus;* and northern redhorse, *Moxostoma aureolum.* Yellow perch, tullibee, and white suckers were the most abundant non-game species in the population.

Winter darkhouse spearing, by which the northern pike used for aging were taken, consists of spearing from inside a windowless and usually heated fish house. A large hole is cut in the ice beneath the fishhouse and pike lured within spearing range by jiggling a large wooden minnow in the water. In Minnesota the season for darkhouse spearing is within the dates December 1 to February 15 but has varied somewhat in actual dates during the years considered.

Reproductive Period of Northern Pike

Detailed field observation in 1952 showed that in this year the northern pike spawning run in Ball Club Lake began on April 17, about seven days before the beginning of the walleye run at the nearby Cutfoot Sioux fish hatchery, and that the northern pike spawning run lasted about 10 days. Time required for incubation of northern pike eggs is usually about two weeks in Minnesota fish hatcheries but may be somewhat longer or shorter depending on water temperatures.

These reproductive periods are similar to those noted by other investigators. Rawson (1932) at Waskeiu Lake in Saskatchewan found that most northern pike spawning occurred in about 12 days (between May 1 and May 12 in the year studied) and that the eggs took about 12 days to hatch. Carbine (1941) reported that the spawning run at Houghton Lake, Michigan, lasted from 15 to 24 days in April.

To relate water levels and strength of northern pike classes produced,

it was necessary to ascertain the dates of the reproductive periods for each of the 7 years considered. To do this, field observations were supplemented by use of observed relationship between the northern pike run in Ball Club Lake and the recorded walleye run in nearby Cutfoot Sioux Hatchery. Northern pike, as observed in 1952, appear to run in Ball Club about 7 days before the walleye run begins. It is estimated, therefore, that the northern pike run in each year began 7 days before the walleye run and lasted for 10 days. The incubation period, on the basis of experience with artificial hatching of northern pike eggs, is here conservatively estimated at 18 days. In relating water levels of each year to the reproductive period of northern pike, the northern pike reproductive period is considered to include 28 days of spawning and incubation beginning 7 days before the beginning of the walleye spawning run. Dates so obtained are shown in Table 1 along with water level data for the same periods.

TABLE 1.—*Approximate dates of northern pike spawning and egg incubation*[1] *Ball Club Lake, 1945-1952*

Year	Spawning period	Egg incubation period
1945	April 7 - 17	April 17 - May 4
1946	April 7 - 17	April 17 - May 4
1947	April 17 - 27	April 27 - May 14
1948	April 11 - 21	April 21 - May 8
1950	April 27 - May 7	May 7 - May 24
1951	April 21 - May 1	May 1 - May 18
1952	April 17 - 27	April 27 - May 13

[1] As obtained by methods described in the text.

RANKING OF NORTHERN PIKE YEAR-CLASS STRENGTH

During each of the darkhouse spearing seasons of the winters 1950-51 through 1954-55, scale samples were collected from representative series of northern pike in the spearers catch. Numbers of fish from which scale samples were taken and aged was 238 in 1950-51, 90 in 1951-52, 196 in 1952-53, 103 in 1953-54, and 78 in 1954-55. Catch by age groups and age-group frequencies, in terms of percentage of the spearers' catch for each year are shown in Table 2. Previously,[1] age-frequency of fish in the spearing catch had been compared with age-frequency of test net catches for specific years. This comparison showed that the percentage composition of the various age-classes in the spearers catch appeared to fluctuate in relation to their comparative abundance in the population as shown by test netting, and that these fluctuations were not dependent on fishing pressure. Therefore, it is considered here that fluctuations in the comparative abundance of various year-classes in the spearers' catch

[1] Johnson, Fritz H. and Arthur R. Peterson. Comparative harvest of northern pike by summer angling and winter darkhouse spearing from Ball Club Lake, Itasca County, Minnesota. Minn Dept. Cons. Fish. Res. Invest. Rept. No. 164, 11 pp. mimeo. 1955.

provide information on the relative abundance of these year-classes in the population.

It will be observed from Table 2 that the percentage of any year-class in the total spearing catch for any winter varies considerably; probably reflecting vulnerability of the fish to spearing, (small fish are not preferred by spearers), effect of previous fishing and natural mortality on a year class, influence of comparative sizes of other year classes on the percentage calculations as well as reflecting the strength of the year class itself. Thus, in the winter of 1950-51 (Column 1, Table 2) fish of age class I made up 5 percent of the catch; age class II, 35 percent; age class III, 31 percent, etc. Because age class I in the winter of 1950-51 became age class II in 1951-52 and age class III in the following year, the problem becomes one of evaluation of strength of year class throughout its history in the fishery.

An approach to such an evaluation is made in Table 3 by adding the percentage strength that each year class made up in the catch for the several years it appeared in the catch. Thus, the 1952 year class made up 4 percent of the catch at Age I and 17 percent of the catch at Age II for a total or aggregate percentage for the two spearing seasons of 21 percent. Similarly, fish hatched in 1951 appeared in the catch during three years as I's II's, and III's for an aggregate percentage of 61. The aggregate percentages for each year class are compared with aggregate percentages based on age-group composition of the catch during the 5 years.[2] Thus, on the average, over the 5 years I's and II's made up 30 percent of the catch while for 1952 I's and II's made up 21 percent of the catch. Division of 21 by 30 gives the index of year class strength of 0.70 in Table 3. It will be noted that these indices of year class strength of 0.70 from a low of 0.70 for the 1952 year class to a high of 1.68 for the 1950 year class. It should be emphasized that these index values are not used as absolute figures but rather as figures for ranking years on basis of comparative strength of year classes. By this method the year rank from high to low in the following order: 1950, 1947, 1948, 1945, 1946, 1951, and 1952.

Ranking of Water Conditions During The Northern Pike Reproduction Period

Ball Club Lake forms a part of a Mississippi River headwater reservoir and is subject to water level control by the Corps of Engineers, U. S. Army. Its level is influenced by three dams; two of which are located on the Mississippi River and one on the tributary Leech River. Spring water levels and water level fluctuations are governed by: (1) the level

[2] Average percentage age-composition of the catch for the five years is expressed in terms of geometric rather than arithmetic means to dampen the effect of large numbers on the average.

TABLE 2.—*Age distribution and year-class composition of the spearing catch of northern pike from Ball Club Lake*

1950-51				1951-52				1952-53				1953-54				1954-55			
Year class	Age group	No. of fish	Pct. of catch	Year class	Age group	No. of fish	Pct. of catch	Year class	Age group	No. of fish	Pct. of catch	Year class	Age group	No. of fish	Pct. of catch	Year class	Age group	No. of fish	Pct. of catch
1949	I	12	5	1950	I	5	5	1951	I	3	2	1952	I	4	4	1953	I	—	—
1948	II	84	35	1949	II	18	20	1950	II	75	38	1951	II	32	31	1952	II	13	17
1947	III	73	31	1948	III	31	35	1949	III	44	23	1950	III	50	48	1951	III	22	28
1946	IV	34	15	1947	IV	29	33	1948	IV	38	19	1949	IV	15	15	1950	IV	30	38
1945	V	17	6	1946	V	4	4	1947	V	22	11	1948	V	1	1	1949	V	7	9
1944	VI	10	4	1945	VI	3	3	1946	VI	12	6	1947	VI	1	1	1948	VI	3	4
1943	VII	7	3					1945	VII	2	1					1947	VII	3	4
1942	VIII	1	1																
Totals		238				90				196				103				78	

of the lake prior to the spring breakup; (2) spring runoff and precipitation; and (3) the regulation of control dams. The level of Ball Club Lake is recorded about once a week by the Corps of Engineers at the Ball Club River immediately below the outlet of the lake. The water level is measured with a steel tape suspended from the bottom of a bridge girder which is considered as 0. Therefore, water level measurements shown in Table 4 are small for high stages and large for low stages; the reverse of what might be expected from an ordinary staff gauge. Mean water levels during the pike spawning period in the 7 years are averaged to obtain an expression of most usual spring conditions. For the 7 years considered the average level for Ball Club Lake during pike spawning was 3.15 feet as measured by the method described. Water level readings for each year were compared with the 7-year average to obtain a water-level index for each year. For example, the mean level for the 7 years was divided into the mean level for the spring of 1945 (1.67) to obtain an index figure of 0.53 which is used as a water level index for that year. It should be noted again that because of the way water level was measured the smaller the index figures in Column 3 of Table IV the higher the water stage.

TABLE 4.—*Spring water level data during the northern pike reproductive period and indices of water level condition*

Year	Mean water level measurement in feet during spawning (Ms)	Index of water level during spawning $\left(\frac{Ms}{s}\right)$	Maximum water level drop in feet during egg incubation (Md)	Index of water level drop $\left(\frac{Md}{D}\right)$	Index of water level conditions $\left(\frac{Ms}{S}+\frac{Md}{D}\right)$
1945	1.67	0.53	1.63	1.58	2.11
1946	4.08	1.28	1.05	1.02	2.30
1947	3.61	1.14	0.98	0.95	2.09
1948	3.10	0.92	1.30	1.26	2.18
1950	2.20	0.70	0.30	0.29	0.99
1951	3.69	1.17	0.66	0.64	1.81
1952	3.70	1.17	1.29	1.25	2.42
Mean....	(S) 3.15		(D) 1.03		

An index of maximum water level fluctuation during incubation period of any year was obtained by dividing range or drop in water levels in any year by the average range or drop from highest to lowest levels for the 7 years considered. Thus, the average decline in water level during the incubation period during the 7 years was 1.03 feet and decline in 1945 was 1.63 feet. Division of the later figure by the former gives 1.58 as an index of water level drop during incubation. The sum of the two water condition index figures shown in the last column of Table 4 is taken as a general index of spring water conditions during the reproductive period.

TABLE 3.—*Calculations of indices of northern pike year-class strength in Ball Club Lake, Minnesota, 1945-1952*[1]

Age Group	Five-year geometric means of age-group percentages in spearers catch	Aggregate percentages for a particular age group	Percentage contribution of various year classes to spearers catch													
			1952		1951		1950		1948		1947		1946		1945	
			Per-cent	Aggre-gate	Per-cent	Aggre-gate	Per-cent	Aggre-gate	Per-cent	Aggre-gate	Per-cent	Aggre-gate	Per-cent	Aggre-gate	Per-cent	Aggre-gate
I	3	—	4	—	2	—	5	—	—	—	—	—	—	—	—	—
II	27	30	17	21	31	—	38	—	35	—	—	—	—	—	—	—
III	32	62	—	—	28	61	48	—	35	—	31	—	—	—	—	—
IV	14	76	—	—	—	—	38	129	19	—	33	—	15	—	—	—
V	5	—	—	—	—	—	—	—	1	—	11	—	4	—	6	—
VI	3	81	—	—	—	—	—	—	4	94	1	—	6	—	3	—
		56	—	—	—	—	—	—	—	—	4	80	—	—	—	—
VII	2	24	—	—	—	—	—	—	—	—	—	—	0	25	—	—
		10	—	—	—	—	—	—	—	—	—	—	—	—	1	10
Index of[2] year-class strength			0.70		0.98		1.69		1.16		1.42		1.04		1.10	

[1] The 1949 year-class was omitted because data on spring water level data were not available for this year.

[2] An index figure of 1.00 represents the calculated average strength of a year-class during the 5 years considered in Table 2.

The relationship just described can be expressed by the following formula:

$$L = \frac{Ms}{S} + \frac{Md}{D}$$

Where

L = Index of water level conditions during the pike spawning and incubation period.

Ms = Mean water level (as explained in text) during the spawning period of a given year.

Md = Maximum water level drop between end of spawning period and end of egg incubation period in a given year.

S = Seven year mean water level (as explained in text) during the spawning period.

D = Seven year mean of maximum decline in water level between end of the spawning period and end of egg incubation period.

It should be noted that the two fractions in the equation are given equal value on an *a priori* basis because there was no way of assigning comparative values to them. As so calculated, the lower the L value the higher and more stable water levels were and presumably the more favorable for pike reproduction. By this method an "average" water condition in the lake would have an index value of 2.00. As shown in Table 4, values so calculated for the 7 years ranged from 0.99 to 2.42 and the years on this basis ranked in goodness for reproduction from high to low as follows: 1950, 1951, 1947, 1945, 1948, 1946, and 1952.

Relationship Between Rankings of Lake Conditions And Northern Pike Year-Class Strength

Ranking of both water level conditions during the reproductive period and strength of resultant year classes is shown in Table 5. Relationship between the two rankings was calculated by rank difference correlation using the formula of Edwards (1946):

$$p = 1 - \frac{6 \Sigma D^2}{n^3 - n}$$

Where:

p = rank difference correlation coefficient

D = rank difference between the variables

n = number of years

The numeral rank of the indices of water level condition and northern pike year-class strength for the 7 years are shown in Table 5. In this ranking the numeral 1 indicates the most favorable water condition and

TABLE 5.—*Ranking of calculated index values for spring water level conditions and strength of related northern pike year classes in Ball Club Lake, Minnesota*

Year and year class	Relative ranking[1] of index of water condition	Relative ranking[1] of index of year class strength	Rank difference squared
1954	4	4	0
1946	6	5	1
1947	3	2	1
1948	5	3	4
1950	1	1	0
1951	2	6	16
1952	7	7	0
Total.....			22

[1] The numeral 1 represents most stable water levels and strongest year class; other numbers are ranked in ascending numerical order.

strongest year class and indicates lowest calculated index values. Other numbers are ranked in arithmetic sequence. Using the above equation, rank difference correlation between northern pike year-class strength and associated water level conditions under which the year class was produced is 0.61. This is a moderate degree of correlation since 0.0 would represent no correlation and 1.00 complete correlation. Lack of closer correlation probably represents uncertainties in the data, unavoidable assumptions in the calculation and influence of factors not considered such as depressing effect of a strong year class upon those following.

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EFFECTS OF TOXAPHENE AND ROTENONE UPON THE MACROSCOPIC BOTTOM FAUNA OF TWO NORTHERN COLORADO RESERVOIRS

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ABSTRACT

Two northern Colorado reservoirs, Reservoir No. 4 and Smith Lake, were treated with fish toxicants to eliminate the rough fish. An investigation was conducted to ascertain the effects of toxaphene and derris (rotenone) upon the macroscopic bottom fauna. Reservoir No. 2 was used as a control. Bottom fauna were collected by four Ekman dredge hauls made on each of the reservoirs at approximately two-week intervals between October 21, 1954, and September 30, 1955.

The application of approximately 0.1 p.p.m. toxaphene had a marked effect upon the Tendipedidae (Chironomidae) population in Reservoir No. 4. Living larvae were absent from the samples within three days following the poisoning. Re-population of the lake was not complete until July, nine months after poisoning. The *Chaoborus* larvae exhibited no immediate effects from the toxaphene, although the larvae were absent from a sample taken six months after poisoning and had not reappeared by termination of the study. The Oligochaetes exhibited no adverse effects from the toxaphene, but rather increased in numbers from the beginning until completion of the study.

The application of approximately 1.0 p.p.m. derris (rotenone) did not affect the tendipedid population of Smith Lake to the extent that toxaphene affected it in Reservoir No. 4. The sample collected three days after the poisoning contained 40 larvae, the majority of which were dead. This was the only sample which indicated any extensive effects of the poison. The oligochaetes exhibited an initial increase after poisoning but the population soon became relatively stable.

Toxaphene had a much greater immediate and residual effect upon the Tendipedidae than did the rotenone. The Oligochaeta were not adversely affected by either poison.

INTRODUCTION

Knowledge of the effects of fish toxicants upon the fish populations is fairly complete, but little is known of what happens to the other inhabitants of the lake when poisons are added. Existing information concerning the effects of these poisons upon the bottom faunas has been brought out as sidelights to fish population studies. This study was undertaken to compare the effects of two toxicants, rotenone and toxaphene, upon the macroscopic bottom faunas of two northern Colorado reservoirs.

The study lakes are located approximately nine miles north of Fort Collins, Larimer County, Colorado. Reservoir No. 4, a single-basin lake with a surface area of about 60 acres, was treated with sufficient emulsi-

fiable toxaphene to give a concentration of 0.1 p.p.m. in the lake. The maximum depth of the reservoir was 14 feet during the greater part of the study. The water level fluctuated to some degree in all three study lakes since they are a part of a system of irrigation storage basins. The surface temperature at the time of poisoning was 42.0°F. Smith Lake, a single-basin, natural lake with a surface area of about 24 acres, was treated with sufficient derris powder, containing five percent rotenone, to give a concentration of 1.0 p.p.m. derris in the lake. The maximum depth of Smith Lake during the study was five feet. Surface temperature at time of poisoning was 38.0°F. The bottom of both lakes is a mixture of silt and finely decomposed organic matter which imparts a black color to the mud. A similar reservoir, Reservoir No. 2, was used for experimental control. The maximum depth of Reservoir No. 2 was seven feet.

A sampling program was conducted from October 21, 1954, to September 30, 1955, to collect chemical, physical, and biological data for the study. Reservoir No. 4 was treated on October 28, 1954, and Smith Lake on November 4, 1954.

Bottom samples were collected every two weeks, weather conditions permitting, by means of a one-quarter square foot Ekman dredge and the samples washed through graduated screens, the smallest having 20 meshes per inch (eight per centimeter). Each sample consisted of one square foot of bottom mud collected by four dredgings equidistantly spaced along a transect extending from the deepest point in the lake to the shore line. Samples for dissolved oxygen, free carbon dioxide, phenolphthalein (ph-th) alkalinity, methyl orange (M.O.) alkalinity, and hydrogen-ion concentration (pH) were collected and analyzed by standard limnological techniques.

Basic Limnology

The water of the two treated lakes was supersaturated with dissolved oxygen during most of the study. The lakes attained their greatest degree of supersaturation during February or March after a relatively sharp rise in January. With the exception of Reservoir No. 4, the oxygen content decreased until sometime in June or July when the lowest values were detected. In Reservoir No. 4, percentage of saturation decreased until May and then increased again to a lesser peak in July (Table 1).

The phenolphthalein alkalinity in Smith Lake and Reservoir No. 2 exhibited downward trends beginning in January or February and reached their lowest values during the summer months. In Reservoir No. 4, the phenolphthalein alkalinity indicated no particular trends, with low and high values being recorded during the winter as well as the summer months.

The methyl orange alkalinity of the three lakes showed a considerable range (30 to 284 p.p.m.) and exhibited trends similar to those noted for phenolphthalein alkalinity. High values were recorded during the colder months and, after a period of decreasing alkalinity, the lowest values were recorded in August and September. The water hardness of the study lakes is due to carbonates and bicarbonates. The pH of the lakes varied from 7.6

to 8.9. The chemical characteristics of the lakes agreed quite closely with those found by Pennak (1945) in his study of several northern Colorado lakes.

The shallowness of the lakes allowed sufficient wind-induced mixing so that thermal stratification did not develop.

Secchi disc readings varied considerably in the two poisoned lakes (Table 1). The lakes began to clear soon after application of the poison and by early winter, two months following poisoning, the bottom of the two treated lakes was visible. The clearing was due to the decrease in amount of suspended silt in the water which had been caused by the activities of the carp *(Cyprinus carpio)*.

Effects of Toxicants on Bottom Fauna

The application of the toxaphene had a marked effect upon the Tendipedidae (Chironomidae) population in Reservoir No. 4. The sample taken on October 29, 1954, the day after the poisoning, contained two living larvae as compared with 22 and 35 larvae in the two samples collected the week prior to the poisoning. This also was the last time that living larvae were collected until re-population of the lake the following July (Table 2). The large masses of dead bloodworms washed up on shore four days after poisoning indicate the immediate effect of the toxicant. Moretti (1948) discovered that *Chironomus* larvae were killed rapidly by toxaphene.

Chaoborus larvae in Reservoir No. 4 exhibited no immediate effects from the poison. Instead of decreasing after the poisoning, the population showed an increase during the months of November and December and were still as numerous in January as at the beginning of the study (Table 2). A sharp decrease was noted in the February sample and by April the larvae were absent. The depletion of the larvae six months after application of the poison is probably not attributable to the toxic action of the poison direct upon the larvae. Hooper (personal communication), however, found that almost the entire population of *Chaoborus* larvae was decimated within a day or two following application of toxaphene to a Michigan lake. This lack of consistency is difficult to explain at this time. Starvation is a possible explanation for the dying off of the larvae since *Chaoborus* are predaceous upon Entomostraca (Coker, 1954). An examination of the Entomostraca population in Reservoir No. 4 showed that the organisms were absent from the surface sample from December until April.[1] In the bottom water, a very small population was present in January and February. The decrease of the *Chaoborus* population began in December and continued until the organisms were absent in April. The population in the control lake remained relatively stable during the winter months and began pupating in spring. No specimens were taken in the August sample during the height of the emergence in Reservoir No. 2, but the larvae were again present in the September sample (Table 4). Here again, the population of chao-

[1]Hoffman, Dale A. 1956. Typewritten M. Sc. thesis. Colorado A and M College. Effects of two piscicides, rotenone and toxaphene, upon plankton of two northern Colorado reservoirs.

TABLE 1.—*Summary of chemical and physical data for the three study lakes, October 21, 1954, to September 30, 1955.*

	Oxygen Saturation (percent)	Phenolphthalein Alkalinity (parts per million)	Methyl-orange Alkalinity (parts per million)	Hydrogen-ion Concentration (pH)	Water Temperature (degrees Fahrenheit)	Secchi Disc (inches)
Reservoir Number Four..... (toxaphene)	74—207	4—17	36—135	8.2—8.9	surface 34.4—75.0 bottom 36.6—73.6	26.5—217.0
Reservoir Number Two..... (control)	74—200	0—18	45—207	7.9—8.5	surface 33.9—71.4 bottom 40.0—69.5	6.0—24.0
Smith Lake..... (rotenone)	65—195	0—30	30—284	7.6—8.9	surface 34.8—72.0 bottom 38.0—71.1	20.5—74.0

borids in Reservoir No. 4 deviated from those in the control lake, in that they did not reappear in the fall. Samples collected subsequent to April contained no larvae.

The Oligochaeta in Reservoir No. 4 showed no adverse effects from the poison. Moretti (1948) found that the oligochaete *Lumbriculus* survived high concentrations of toxaphene.

The population in Reservoir No. 4 increased from the beginning to the completion of the study. The utilization of the organic matter contributed by the decomposed bodies of the poisoned fish which fell to the bottom may be a contributing factor in the population increase. Morgan (1930) stated that most oligochaetes subsist on decayed organic matter. According to Pennak (1953), oligochaetes obtain nutriment by ingesting quantities of the substrate. The food may consist largely of filamentous algae, diatoms, or miscellaneous plant and animal detritus. Oligochaetes were not present in sufficient numbers in Reservoir No. 2 to permit a comparison.

The abundant growth of aquatic vegetation which followed the poisoning of Reservoir No. 4 was probably due to a combination of two factors. First, the clearing of the lake permitted sufficient sunlight for photosynthesis to reach all parts of the lake bottom, and secondly, the increase in organic matter from the decomposed bodies of the poisoned fish acted as a fertilizer for the plants. Bennett (1943) reported that dense mats of pondweed *(Potamogeton foliosus)* appeared in his study lake following the destruction of rough fish and subsequent clearing of the water. The vegetation, however, grew only in the shallower water and was limited to a depth of about five feet. In Reservoir No. 4, the same species of pondweed was the dominant vegetation, but the plants grew in all depths of the lake.

Rotenone did not affect the tendipedid population of Smith Lake to the extent that toxaphene affected it in Reservoir No. 4 (Table 3). The sample collected November 7, 1954, three days after the poisoning, contained 40 larvae, the majority of which were dead. Although the two subsequent samples contained dead larvae, the majority were alive.

Brown and Ball (1943) found that a concentration of one part derris to 500,000 parts of water (2.0 p.p.m.) was fatal to Chironomidae, although death may have resulted from unfavorable conditions resulting from the change of habitat. Fellton (1940) discovered that concentrations of 6.0 p.p.m. and 10.0 p.p.m. derris (rotenone) were toxic to chironomid larvae. Hooper (1948), and Smith (1940, 1941, and 1950) discovered that concentration of 0.5 p.p.m. derris, 0.25 p.p.m. derris, 0.5 p.p.m. derris, and 0.025 p.p.m. rotenone, respectively, were not toxic to most bottom fauna or aquatic invertebrates. Leonard (1939) found that 1.0 p.p.m. of derris was not toxic to the genus *Chironomus* in a laboratory experiment.

The results of the application of approximately 1.0 p.p.m. of derris to Smith Lake agree quite closely with those of the above authors. The immediate effects of the poison indicate that the concentration may have been slightly in excess of 1.0 p.p.m. since most of the larvae in the

sample collected on November 7, 1954, three days after poisoning, were dead. Since these effects were short-lived, however, the concentration was probably very close to the calculated 1.0 p.p.m.

The oligochaete population in Smith Lake did not attain the size of the population in Reservoir No. 4. The populations in both lakes demonstrated upward trends early in the study, but, while the oligochaetes in Reservoir No. 4 continued to increase, the population in Smith Lake attained a somewhat stable condition. Hooper (1948) found an increase in the oligochaete population after application of derris root (rotenone). This increase, however, was not attributed to any effects of the poison.

Aquatic vegetation in Smith Lake grew in scattered bunches throughout the lake, quite unlike the solid mass in Reservoir No. 4. Here again, the amount of organic matter present for fertilizer may have been a contributing factor. Sufficient sunlight was present at all depths for photosynthesis.

The application of toxaphene to Reservoir No. 4 and derris (rotenone) to Smith Lake produced different results. The tendipedid population in Reservoir No. 4 was eradicated by toxaphene, that of Smith Lake was affected only temporarily and to a much lesser degree by rotenone. Repopulation of Reservoir No. 4 by midge larvae did not occur until nine months following the poisoning. The population in Smith Lake exhibited

TABLE 2.—*Bottom fauna; numbers of organisms per square foot in Reservoir No. 4, October 21, 1954, to September 30, 1955.*

Date	Tendipedidae (Chironomidae)	*Chaoborus*	*Palpomyia*	*Physa*	Oligochaeta
10-21-54	22	82	0	0	0
10-26-54	35	49	0	0	2
10-29-54	21 (2 alive)	90	0	0	7
10-31-54	9 (dead)	24	2	0	3
11- 4-54	15 (dead)	120	0	0	2
11-11-54	11 (dead)	109	1	0	9
11-21-54	3 (dead)	104	0	0	5
12-22-54	0	89	6	0	10
1- 8-55	0	71	0	0	42
1-22-55	0	49	0	0	12
2- 5-55	0	31	0	0	—
2-25-55	0	11	0	0	37
3- 4-55	0	23	0	0	53
3-19-55	0	3	0	0	82
4- 2-55	0	1	0	0	68
4-16-55	0	0	0	0	63
4-30-55	0	0	0	0	140
5-15-55	0	0	0	0	108
5-29-55	1	0	0	0	203
6-22-55	0	0	0	0	127
7- 6-55	14	0	0	0	112
7-20-55	21	0	0	4	167
8- 3-55	45	0	0	2	186
8-24-55	50	0	0	9	126
9-14-55	14	0	0	15	277
9-30-55	20	0	0	7	330

TABLE 3.—*Bottom fauna; numbers of organisms per square foot in Smith Lake, November 4, 1954, to September 30, 1955.*

Date	Tendipedidae (Chironomidae)	*Chaoborus*	*Palpomyia*	*Physa*	Oligochaeta	*Hyallela*	*Chrysops*
11- 4-54	33	0	0	0	0	0	0
11- 5-54	32	0	1	0	0	0	0
11 -7-54	40 (mostly dead)	0	0	0	0	0	0
11-11-54	31	3	0	0	0	0	0
11-20-54	20 (9 dead)	3	0	0	0	0	0
1- 8-55	18	0	1	0	1	0	0
1-21-55	14	6	1	0	5	0	0
2- 5-55	24	1	0	0	0	0	0
2-22-55	12	4	0	0	31	0	0
3- 4-55	17	5	0	0	49	0	0
3-19-55	27	2	1	0	19	0	0
4- 2-55	27	1	0	0	34	0	0
4-16-55	13	1	1	0	22	0	0
4-30-55	8	2	3	0	29	0	0
5-15-55	25	0	3	0	43	0	0
5-29-55	1,024	3	0	0	34	1	0
6-22-55	252	1	3	0	7	0	0
7- 6-55	408	0	1	0	26	0	0
7-20-55	16	0	0	6	31	0	0
8- 3-55	43	0	0	8	13	0	0
8-24-55	68	0	4	4	11	0	0
9-14-55	8	0	1	0	47	1	4
9-30-55	26	0	2	2	26	0	0

TABLE 4.—*Bottom fauna; numbers of organisms per square foot in Reservoir No. 2, October 21, 1954, to September 30, 1955.*[1]

Date	Tendipedidae (Chironomidae)	*Chaoborus*	*Palpomyia*	*Physa*	Oligochaeta
10-21-54	37	45	0	0	2
10-26-54	98	22	0	0	0
11-11-54	144	43	0	0	2
11-21-54	120	37	0	0	1
1- 8-55	136	46	0	0	1
1-21-55	141	38	0	0	1
2- 5-55	121	35	0	0	4
2-24-55	165	33	0	0	2
3- 4-55	159	67	0	0	3
3-19-55	147	55	0	0	1
4- 2-55	120	30	0	0	0
4-16-55	141	54	0	0	0
4-30-55	118	29	2	0	1
5-15-55	66	19	0	0	1
5-29-55	38	26	0	0	1
6-22-55	6	3	0	0	1
7- 6-55	43	3	0	0	1
7-20-55	128	1	0	0	4
8- 3-55	80	0	0	1	0
8-24-55	11	0	0	0	0
9-14-55	12	14	0	0	3
9-30-55	39	18	2	0	7

[1]Not treated with either toxaphene or rotenone.

only short-lived effects, in that the sample collected three days following poisoning was the only collection in which the larvae exhibited any extensive effects of the poison. The oligochaete population in both lakes increased after application of the poisons. In general, toxaphene produced greater immediate and residual effects upon the bottom faunas than did the rotenone.

Acknowledgments

The authors would like to express their appreciation to the Colorado Game and Fish Department for providing equipment and poisoning the lakes; the Department of Zoology, Colorado A and M College for making the necessary facilities available and to the Colorado A and M. Research Foundation for contributing financial help in the form of a fellowship grant.

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OBSERVATIONS ON THE FOOD AND GROWTH OF JUVENILE AMERICAN SHAD, *ALOSA SAPIDISSIMA*[1]

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ABSTRACT

Previous studies on the food habits of juvenile American shad have been restricted to one area such as an individual river or a group of ponds. In this study juveniles were obtained from six widely separated rivers. It was found that the food taken, mostly insects and crustaceans, was approximately the same in all rivers sampled. In general young shad appeared to utilize those food organisms which were most available in their habitat at a particular time. Phytoplankton was not observed in any of the 453 stomachs examined. The average lengths of the shad sampled from the various rivers, excluding the Pamunkey River sample, were similar although the southern river samples spawned earlier than those from the more northern rivers.

INTRODUCTION

The American shad *(Alosa sapidissima)* is an anadromous fish that spends most of its life in the sea. Each spring the sexually mature adults return to their native stream to spawn. The new year-class spends its first summer and early fall in the river and then returns to the ocean. Details on the life history of shad can be found in the papers of Leim (1924).

During August, 1954, juvenile shad were obtained from several rivers along the Atlantic Coast to determine if there were differences in average growth and types of food taken. A sample of shad was also taken in October at one of the stations. To the author's knowledge no previous coast-wise comparison of this type has been made. Mitchell and staff (1925), examined the stomachs of young shad taken from the Connecticut River and a nearby pond and concluded that insects and crustaceans were the mainstay of the diet. Leim (1924) examined the stomach contents of 40 juvenile shad, 24-25 millimeters in length, taken from the Shubenacadie River in Nova Scotia. Their food consisted mainly of plankton such copepods, amphipods, cladocerans, insect larvae, ostracods,

[1]The shad investigation of the U. S. Fish and Wildlife Service, of which this study is a part, is being carried on to furnish information for fishery regulations to the Atlantic States Marine Fisheries Commission.

and water mites. Maxfield[2] studied the food habits of juvenile shad reared in ponds in Maryland and found that the major food items were ostracods, insects, insect larvae, copepods, and cladocerans.

Sampling Methods

The rivers sampled in this study were the St. Johns in Florida, the Ogeechee in Georgia, the Neuse in North Carolina, the Pamunkey in Virginia, the Hudson in New York and the Connecticut in Connecticut. Samples were obtained with a surface trawl similar to that described by Massmann, Ladd, and McCutcheon (1952) in all the rivers except the Hudson River where a portion of the sample was obtained with a 20-foot beach seine. The trawl sampling was done after sunset because daylight trawling yielded few shad.

Specimens were removed from the net and preserved in 10-percent formalin. The majority of young shad had suffocated before their introduction into formalin and therefore, regurgitation of stomach contents was at a minimum. Samples were taken to the laboratory where specimens were measured (fork length in millimeters) and the stomachs were removed at random from one-half the individuals in each sample. It was assumed that the results obtained through the study of one-half the sample would be representative of the food taken by the entire sample. Samples from each river were kept separate. Stomach contents were examined with a binocular microscope. In all 453 stomachs were examined, each of which contained some type of food.

Food of Juvenile Shad

In this study the frequency-of-occurrence method was used to express the type of food present. The percentage of stomachs in each sample containing a given organism is tabulated in Table 1. Frequently copepods, cladocerans, and many of the insects were considerably broken up and often only a portion of the bodies of food animals could be found. This often made complete identification difficult or impossible.

The St. Johns River sample was taken from three locations; Lake Monroe, Georgetown, and Mandarin. The stomachs from this sample which were examined contained little food. The food taken consisted of ostracods, hymenopterans, insect larvae and unidentifiable insects. Marine decapod larvae were found only in the sample taken at Mandarin, which is nearer to salt water than the other locations. Ostracods were noticeably absent from this latter sampling location.

The stomachs obtained from the Ogechee River fish contained little food. The material found in them consisted mainly of unidentifiable insects and animal residue, plus cladocerans and marine decapod larvae.

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[2]Maxfield, G. H. 1952. The food habits of hatchery-produced pond-cultured shad (Alosa sapidissima) reared to a total length of two inches. Masters Thesis, Univ. of Wash.

In the August sample from the Neuse River there was much variation in the type of food taken as well as the amount of food found in the individual stomachs. Crustacean eggs and mayflies made up the bulk of the identifiable material. The Neuse River sample taken in October indicated a much different diet from that found earlier. Stomach contents of fish in the fall sample consisted almost exclusively of insects, excluding Ephemerida. Unidentifiable small fish were also present in some of the stomachs; small cyprinid minnows and anchovies (*Anchova* sp.) 10 to 20 millimeters in length. Mitchell and staff (1925) also reported finding small fish—various minnows, small sunfish (*Lepomis* sp.) in the stomachs of young shad. The occurrence of fish in 24 percent of the October collections from the Neuse River indicates that the ability of juvenile shad

TABLE 1.—*Frequency of occurrence of various food items in stomachs of juvenile shad, expressed as percentage of number of fish examined*

Location	St. Johns River	Lake Monroe	Georgetown	Mandarin	Ogeechee River	Neuse River	August sample	October sample[1]	Pamunkey River	Hudson River	Surface trawl	Beach seine	Connecticut River	Below Enfield Dam	Above Enfield Dam
Type of food															
Decapod larvae	—	—	—	38	17	—	2	13	5	—	—	—	—	—	—
Copepoda	—	12	7	4	—	—	—	7	—	—	28	3	—	57	100
Ostracoda	—	47	93	—	—	—	14	—	22	—	24	—	—	2	7
Cladocera	—	6	—	42	20	—	4	—	—	—	4	—	—	76	84
Crustacean eggs	—	12	7	4	—	—	27	6	3	—	4	13	—	60	42
Ephemerida	—	—	—	—	—	—	25	—	74	—	—	—	—	—	5
Homoptera	—	—	—	—	—	—	2	54	—	—	—	33	—	—	—
Hemiptera	—	—	—	—	5	—	—	4	—	—	—	13	—	—	—
Hymenoptera	—	65	50	13	—	—	8	85	4	—	8	17	—	12	5
Coleoptera	—	—	—	—	6	—	—	17	1	—	—	13	—	—	—
Diptera	—	—	—	—	8	—	4	48	—	—	36	80	—	42	32
Diptera larvae	—	—	—	—	—	—	—	4	1	—	32	77	—	—	—
Diptera pupae	—	—	—	—	—	—	—	4	1	—	—	23	—	14	—
Insect eggs	—	—	—	—	—	—	—	—	59	—	—	—	—	—	—
Unidentifiable insects[2]	—	24	57	38	28	—	20	15	18	—	60	37	—	43	26
Miscellaneous insect larvae	—	35	36	21	11	—	8	—	—	—	—	—	—	67	5
Nematoda	—	—	—	—	6	—	—	—	25	—	8	20	—	21	—
Unidentifiable animal remains	—	—	—	—	22	—	22	—	4	—	—	—	—	—	—
Araneida	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—
Fish	—	6	—	—	—	—	—	24	1	—	—	—	—	—	—
Fish larvae	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—
Number of stomachs examined	—	17	14	24	65	—	51	54	112	—	25	30	—	42	19

[1]This sample was taken at the same location as the August sample.
[2]Partially digested.

to take fish as food may increase with an increase in length. The mean length of the 98 juvenile shad collected in August from the Neuse River was 51 millimeters (range 35-83) while that of the 55 juveniles collected in October from this same river was 75 millimeters (range 62-93).

The stomachs of young shad taken from the Pamunkey River were generally full. The main diet at the time of sampling was Ephemerida and insect eggs. Nematoda and Ostracoda were also well represented in the sample.

The Hudson River trawl sample was taken in a cove where the water averaged about six feet in depth. The stomachs of these shad contained little food while those from the shore-seine sample were full. The sample from the cove contained ostracods, copepods, and insects while insects made up most of the food in the beach area.

The sample from the Connecticut River was taken both above and below Enfield Dam near Thompsonville, Connecticut. The stomachs of the shad taken from the impounded area were full and the food consisted of copepods and cladocerans and a few insects. The sample from below the dam showed a preponderance of insects and insect larvae with few crustaceans.

It is evident from the data that the diet of juvenile shad is diversified. Insects and crustaceans seem to be the main dietary items in rivers but the food differs somewhat in any river and in different rivers. Apparently juvenile shad will utilize those food organisms which are most available in the habitat at a particular time. Phytoplankton was not observed in any of the 453 stomachs examined in this study. This finding is in agreement with Maxfield[2] who stated that the absence of algae in the digestive tracts suggests that young shad seek out zooplankton in preference to phytoplankton as food.

Growth of Juvenile Shad

The fork length was determined for all shad in each sample and averages and ranges of these measurements are shown in Table 2. Assuming that

TABLE 2.—*Length of juvenile shad taken from several Atlantic Coast rivers, 1954*

River	Date of collection (August)	Number of fish taken	Fork length (millimeters)	
			Range	Average
St. Johns	9-11	112	39-74	54
Ogeechee	13	130	42-76	55
Neuse	17-18	98	35-83	51
Pamunkey	20-23	223	47-85	65
Hudson	29	110	45-65	54
Connecticut	27-28	217	37-84	54

the sample from each river was representative and a true indication of juvenile-shad growth, comparisons of growth in the different rivers can be made. In the Pamunkey River juvenile shad were of a larger average size (65 millimeters) and in the Neuse River of a smaller average size (51 millimeters) than in the other streams. In the other streams the average lengths of the fish in August were 54 and 55 millimeters. Similarity of average lengths in the different rivers was unexpected because the peak of shad spawning in the St. Johns River is in March, whereas the peak in the Connecticut River occurs in May.[3] On the basis of age alone, an increase in average length from north to south would be expected. Apparently environmental factors may cancel out growth differential which might be expected from differences in spawning dates.

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PELLETED DRY RATIONS FOR TROUT PROPAGATION IN MICHIGAN HATCHERIES[1]

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Abstract

Diets of pelleted animal and vegetable meals were compared with dry-meal and chopped raw-meat diets as food of rainbow and brook trout. Evaluation was made by bimonthly measurement of weight and length, daily mortality, and physiological changes. Pelleted dry-meal diets were not accepted immediately as food by rainbow and brook trout. This was evidenced by a loss of weight during the first two weeks of feeding pelleted food. Lost weight was regained after four weeks of feeding. All dry-meal ingredients pelleted in the combinations used were acceptable as trout food when supplemented with raw beef liver at least one day every three weeks. Dry diets resulted in no reduction of growth rates when fed at one-half to five-eighths the amounts recommended for raw-meat mixtures. A diet containing brewers yeast produced a greater gain in weight of rainbow trout than an otherwise identical diet containing torula yeast. Also, it was found that a pelleted diet was superior to a raw beef liver diet. The adoption of dry pelleted diets as standard rations by all state fish hatcheries in Michigan increased trout production in pounds by 60 percent and reduced fish food expenditures by 40 percent.

Introduction

Almost all trout diets before 1951 consisted of raw meat and raw meat-meal mixtures. Dry concentrates such as vegetable and animal meals were mixed with raw meat in various combinations to reduce the cost per pound of trout raised (McCay, 1937a and 1937b). Nevertheless, food loss from particle separation in water, high labor costs and expensive refrigeration units, meat choppers and mixing units still remained. As the demand for hatchery-reared trout increased, investigations were started to reduce further costs of trout production. In Michigan, investigations to determine the practicability of feeding dry meals in the form of pellets began in 1952. Results of the preliminary feeding tests were satisfactory and further experimentation on a wider scale was started in January of 1953.

The study was directed toward: (1) developing a practical, economical, pelleted, dry-meal diet which could be used to produce healthy, legal-

[1]Contribution from the Institute for Fisheries Research.
[2]Present address: Commercial Solvents Corporation, 260 Madison Avenue, New York 16, New York.

sized trout in the shortest time possible, and (2) elimination of the need for raw meat.

From animal and vegetable products of known nutritional value products were selected with consideration for availability, cost, nutrient quality and bulk, and were mixed in various combinations and tableted. Skim milk, cottonseed meal, wheat flour middlings, soybean meal, brewers and torula yeasts, and fish meals were investigated most extensively. After tableting, physical properties of each mixture were tested in a glass tube eight feet high and two inches in diameter filled with water. Tablets were placed in the water at the top of the tube and allowed to sink to the bottom. The time required to sink from the top to the bottom of the tube and the condition of the tablet with respect to the disintegration at various distances from the top were noted to evaluate physical properties. Tablets were prepared of 20 diet combinations. All tablets were ¼ inch long but were of three diameters: 3/32, 1/8 and 3/16 inch (Grassl[5]). Of the 20 diet combinations the following had the best physical properties: 38 parts by weight fish meal, 5 skim milk, 23 wheat middlings, 5 torula yeast, 25 cottonseed meal, 3 condensed fish solubles, and 2 iodized salt. When pellets were placed in water, no immediate disintegration took place, and they remained intact for as long as 10 minutes. This mixture was pelleted by a local feed manufacture for trout feeding trials and will be referred to hereafter as Diet 1.

Preliminary feeding trials with Diet 1 were made to: (1) compare diet performance of an all-meat diet with an all-pellet diet when fed to rainbow trout, and (2) provide tentative data on pellet size preference. Eighteen pounds of rainbow trout *(Salmo gairdneri)* were placed in each of four concrete tanks at the Hastings State Fish Hatchery preparatory to feeding. These fish had an average length of 4.5 inches and an average weight of 18 grams, and had previously been fed on a meat diet. Each of three lots of fish was fed a different size of pellet, and the fourth was fed a raw pork liver diet as a control. Experimental feeding continued over an 8-week period. All fish were counted before and after the 8-week period. Once a week, the four groups of fish were weighed. The length and weight of every fish that died was recorded. Diet 1 was fed without meat supplementation. All groups were fed more food than was required and at no time during the experiment was all of the food consumed.

Figure 1 shows the growth rate of rainbow trout when fed Diet No. 1 in pellets of three different sizes and with trout fed pork liver as a control. The curves represent average weekly weight gains of individual fish as determined from total weight of each group of trout at the end of each week and the number of fish.

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[5]Grassl, Edward F. 1956. Pelleted dry rations versus standard meat rations for trout. Ph.D. Thesis. Michigan State University. 113 pp.

Sudden change from a soft meat diet to a hard pellet diet was reflected in loss of weight during the first two weeks of experimental feeding.

Preliminary Experiments with Pelleted Diets

In 1952, feeding trials were begun at the State Fish Hatchery, Oden, Michigan, to compare the nutritive value of a commercially pelleted trout food[3] with one of Michigan's standard hatchery diets. Brook trout *(Salvelinus fontinalis)* approximately 6 inches long were used as test animals. Feeding trials extended over two periods: the first, from February to June of 1952, a period of 20 weeks; the second, from November, 1952 to May, 1953, a period of 28 weeks, The standard hatchery diet consisted of 50 parts pork spleen and 50 parts commercial chick starter. The pellet-fed group received pellets four days and raw meat one day per week. Meat was fed in amounts double those of the daily allowance of pellets.

Both diets produced slow growth but the pellet-fed groups showed a greater gain in weight than those on the standard diet, probably because of difference in the physical rather than the nutrient quality of the diets. Ground raw meat particles tend to separate upon contact with water. and it is likely that the trout were able to derive more nutritive benefit from the pellets, which did not disintegrate rapidly.

Other important advantages of pelleted fish food were observed. Pellets could be fed as purchased and could be stored without refrigeration. After ingestion all the nutrients in pellets were available to the fish. Since raw meat was fed only periodically, little time was required for preparation of it. Pelleted food was consumed more completely, which reduced the degree of pond pollution and therefore, less labor was required for pond-cleaning. Because of these major advantages, a pelleted diet was formulated to furnish, as nearly as possible, the required nutrients for normal trout growth and survival.

The first experimental pellet diet, Diet No. 1, was based as much on physical properties of dry ingredients that favored manufacture of pellets as on potential nutritive value. The first step was to determine experimentally which combination of dry meal ingredients, known to have been used as raw-meat supplements, would produce a functional pellet. The desired pellet was one which would disintegrate slowly or not at all in water and which would not sink rapidly to the bottom of a tank or raceway. Preliminary studies were carried out to determine which combinations of ingredients when compressed performed as desired in water.

Because small pelleting machines were not available, a hand-operated

[3]Trade name "Headtide," manufactured by Headtide Fish Food Company, Eastport, Maine.

"Eureka" tablet machine was used which produced one tablet at a time. On a production scale, steam aids in compression and extrusion of dry meals as compact pellets. With the tablet machine, it was impractical to use steam as a humidifier, so a small amount of water was added to the meal mixtures.

As shown in Figure 1 it was necessary to feed the 1/8- and 3/16-inch pellets four weeks before lost weight was regained, whereas only two weeks were required for the group receiving 3/32-inch pellets. Even though the group fed 3/32-inch pellets recovered more quickly than the others, the group fed 1/8-inch pellets showed a steadier gain in weight after recovery. The control group did not lose weight, but gained steadily throughout the experiment.

It is believed that the curves shown in Figure 1 are reliable as to weight loss and gain but do not show conclusively that a particular size pellet was preferred by 5-inch fish. They do show, however, that any of the three pellet sizes used will allow survival and growth of 5-inch trout for eight weeks. As determined by loss and gain of weight per unit of time, rainbow trout should be allowed a 2- to 4-week adjustment period when changing from a meat to a pellet diet of the type used.

The results of these experiments were encouraging enough to warrant further work on development of pellets of better nutritional value for trout.

Evaluation of Seven Pelleted Diets for Rainbow Trout

Materials and Methods

In 1953, large scale feeding experiments with rainbow trout were carried out at the Wolf Lake State Fish Hatchery, 10 miles west of Kalamazoo, Michigan. Clear water is supplied the hatchery from a large spring. The water is held in a pond from whence it flows through underground metal pipes to the hatchery building. In the hatchery, the water temperature varied from 42° to 58° F. during the year. Concentration of dissolved oxygen was between 6.0 and 9.0 p.p.m. and free carbon dioxide averaged 2.2 p.p.m. The pH varied between 7.5 and 8.1, and methyl orange alkalinity was 160 p.p.m.

Twelve concrete tanks and 16 wooden troughs were used for the study. Each concrete tank measured 25 by 2.5 by 3.2 feet and was divided into two individual water-tight compartments that measured 11.5 by 2.5 by 3.2 feet. Each compartment had an individual water inlet and outlet. The rate of flow was regulated by two 1-inch gate valves inserted in a feeder line of 2-inch pipe. Each of the 16 wooden troughs measured 32 by 6.5 by 14 inches. One end was fitted with a 2-inch galvanized metal outlet tube directly in front of which was inserted a screen of six meshes to the inch. At the opposite end water entered through a 1/2-inch

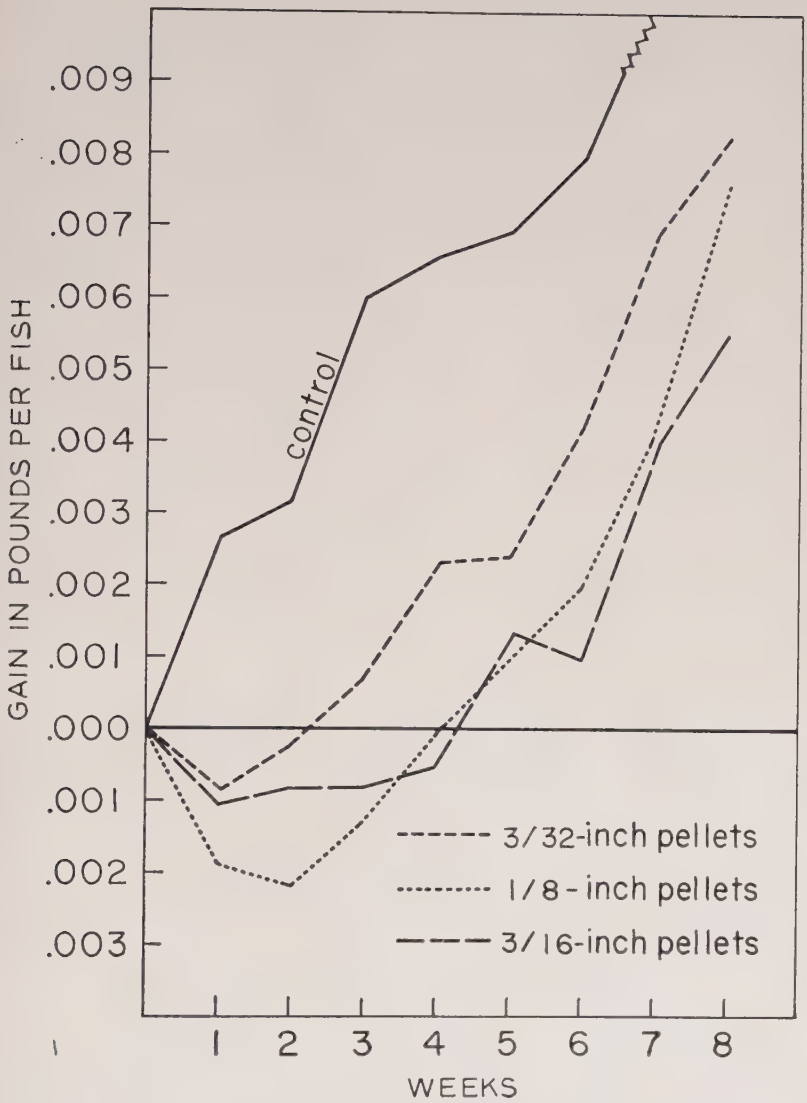

FIGURE 1.—Loss and gain in weight of 5-inch rainbow trout fed a dry-meal diet pelleted in three sizes compared with control diet of pork liver.

spigot from a 2-inch feeder pipe line. A ¼-inch-mesh screen was placed directly beneath each inlet spigot to collect incoming debris. All troughs were completely covered by a framed ¼-inch-mesh screen. Flow of water entering individual troughs was restricted to eight gallons per minute. The source of water for troughs was the same as for the tanks. No attempt was made to filter out small organisms entering the hatchery building with the water supply.

The first phase of the experimental feeding was carried out in small troughs; the second, in large tanks inside the building; the third, in outside concrete and gravel-bottom raceways on a semi-production scale. For the third phase, tests were run in raceways both at the Wolf Lake Hatchery (Michigan's most southerly trout hatchery) and at the Marquette Hatchery (the most northerly). Finally the results were subjected to full-scale hatchery feeding in all Michigan trout hatcheries.

The small troughs were used for preliminary tests on new diet ingredients and/or combinations. Experimental diets were fed to small lots (3 pounds) of trout long enough to determine whether the food had sufficient nutritive value to warrant further investigation. If it was determined that the diet warranted further investigation, a more extensive experiment with larger numbers of fish was carried out in the large concrete tanks. For these experiments 12,000 rainbow trout seven months old and ranging from 2.9 to 5.9 inches in total length and from 4 to 20 grams in weight were used. One thousand fish were placed in each of the 12 tanks previously described. Diet of the fish prior to the experiment was raw beef liver, sheep liver and pork spleen in various combinations. The period of investigation included 14 two-week periods and extended from October 1, 1953, to April 28, 1954.

Seven different combinations of dry animal and vegetable meals (Tables 1 and 2) were compressed into 3/32-inch pellets at the beginning of the experiment and were used until the fish were large enough to accept ⅛-inch pellets. At this time the remaining 3/32-inch pellets were returned to the feed mill, crushed, and repelleted in ⅛-inch size. This size pellet was used for the remaining experimental period.

Originally the proportion of ingredients in the pellets had been selected primarily for their pelleting properties and because it had been established that Diet 1 would support trout life, all other diets were prepared as modifications of it. As shown in Table 1, the base of the seven experimental diets was red fish meal and wheat flour middlings. To this base were added in different amounts the diet variables: yeast, cottonseed meal, soybean meal, condensed fish solubles, xanthophyll, stabilized fat, and gelatin. Each diet contained one or more variables. Diets 1, 2, 3, and 4 were fed to duplicate groups of trout and Diets 5, 6, and 7 to single lots of fish. Diet 8, the control, was beef liver. The experiments were designed to test the mixed diets and not the value of a specific diet ingredient. However, several diet ingredients can be evaluated

TABLE 1.—*Pelleted diet composition (parts by weight)*

Ingredients	Diet Number 1						
	1	2	3	4	5	6	7
Red fish meal	38	38	40	40	40	36	36
Cottonseed meal	23	23	..	..	23	..	..
Wheat flour middlings	25	25	26	26	25	22	22
Torula yeast	5	..	..	5	3	3	3
Brewers yeast	..	5	5	..	3	3	3
Condensed fish solubles	3	3	..	..	3	3	3
Skim milk	5	5	5	5	5	5	5
Iodized salt	2	2	2	2	2	2	2
Soybean oil meal	..	..	23	23	..	25	25
Xanthophyll	..	..	..	..	0.2	..	..
Gelatin	..	..	..	..	..	2	..
Stabilized fat	..	..	..	..	..	..	2

when gain in weight and mortality are used as criteria of diet performance. For this reason, emphasis was placed on performance as determined by duplicate experimental runs by which dry pelleted meal diets, supplemented periodically with raw beef liver could be compared. Proximate food analysis of the seven diets and the control is shown in Table 2.

After pelleting the food was stored in a cool, relatively dark, dry place. The amount fed per day was based on percentage of body weight. The control group was started at a 6.0-percent level and all others at a 3.0-percent level. Since definite feeding levels have not been established for pelleted foods, the levels used here were tentative. They were determined by calculating the dry equivalents of the levels suggested for raw meats by Deuel, Haskell, and Tunison (1942). Measurement of amounts of foods fed was by a metal container marked at a level which corresponds with the desired weight of food for each feeding. Although this procedure may have introduced minor errors, it eliminated the necessity for weighing many small amounts of pellets or ground raw liver.

TABLE 2. — *Proximate analysis of various diets (in percent by weight)*

Diet Number	Moisture	Crude protein	Ether extract	Fiber	Nitrogen-free extract	Ca	P	Ash
1	8	39.6	5.08	4.70	25.2	3.20	2.10	13.30
2	8	39.3	4.40	4.90	25.3	2.90	2.00	12.80
3	8	40.8	4.23	2.27	27.1	3.34	1.91	13.43
4	8	40.8	4.22	2.27	27.1	3.34	1.91	13.43
5	8	41.9	5.36	4.99	26.3	3.36	2.06	13.80
6	8	41.8	3.84	3.28	25.8	3.05	1.78	12.78
7	8	40.3	5.84	3.28	25.8	3.05	1.78	12.78
8 wet	70	20.2	3.10	0.00	6.0	0.01	0.36	1.30
8 dry	0	66.6	9.99	9.00	20.0	0.02	1.30	4.32

All fish were allowed to adjust to the pelleted food over a period of four weeks. Each morning before feeding all tanks and troughs were cleaned and dead trout were counted, weighed and measured. The cause of death was determined when possible. A Fairbanks-Morse platform scale of 1,000-pound capacity was used to weigh each lot of fish at two-week intervals. All fish were weighed in a container sufficiently large to hold a volume of water plus the fish. The water was weighed before adding the fish, and weight of fish was determined by the difference. When fish were dipped from tanks for weighing, excess water was allowed to drain from the net and its contents for about 15 seconds.

The amount of food fed per day was held constant throughout the experiment because it was observed near the beginning that not all the food was consumed. This partially invalidates the conversion factors. But establishment of a definite feeding level was considered to be more important than accurate determination of conversion factors. The tanks used were large enough to compensate for increase in growth so no "thinning" was carried out.

Feeding schedules included four feedings of pellets per day for four days and raw beef liver on one day each week. The control group received raw beef liver four times per day, five days a week. Due to conditions beyond the control of the investigator, all food was withheld on Saturday and Sunday. The usual practice of adding water to ground raw beef liver before feeding was not followed; the liver was fed as it came from the meat chopper. This reduced the amount of particle separation during feeding.

Regression analysis, standard error of estimate, and "t" values according to the method of Snedecor (1946) were used for statistical analysis of differences in the percentage gain in weight between groups fed pelleted diets and a raw beef liver diet and between groups fed various pelleted diets.

Comparison of Gains in Weight of Rainbow Trout Fed on Different Diets

Performance of fish on Diets 1 to 8 inclusive are summarized in Table 3. Results of feeding Diets 1, 2, 3, and 4 concurrently to two different groups of rainbow trout are included to show variations between groups fed the same diet. Conversion factors are calculated by dividing the total pounds of food fed for the twenty-eight week period by the total weight gain as pounds of fish. Percentage gain is calculated by dividing the total gain in weight of fish during a period by the weight at the start. Other entries in the table are self-explanatory.

A graphic comparison of percentage gain in weight in relation to average water temperature and amount of food fed is given in Figure 2. The curves represent the results of feeding Diet 2 and Diet 8 (the best

TABLE C.—*Effectiveness of various diets during a period of 28 weeks when fed to individual lots of v,000 rainbow trout at average water temperature of 47° F.*

Item	Diet Number											
	1	1	2	2	3	3	4	4	5	6	7	8
Number of fish at end	863	864	911	880	963	922	816	934	..[1]	823	..[1]	948
Weight at end (pounds)	144.9	144.4	164.0	163.5	169.0	133.5	115.0	139.0	130.5	134.0	156.0	158.5
Weight at start (pounds)	39.6	39.3	39.9	36.6	38.1	36.5	29.1	35.5	34.5	31.3	38.5	39.5
Gain in weight (pounds)	105.3	105.3	124.1	126.9	130.9	97.0	85.9	103.5	96.0	102.7	117.5	119.0
Cost per pound of food	$0.07	$0.07	$0.08	$0.08	$0.08	$0.08	$0.08	$0.08	$0.07	$0.08	$0.08	$0.14
Conversion[2]	2.4	2.4	1.4	1.4	1.3	1.6	1.6	1.5	1.6	1.5	2.0	3.0
Cost per pound of fish gain	$0.16	$0.16	$0.11	$0.11	$0.11	$0.12	$0.13	$0.13	$0.11	$0.12	$0.16	$0.42
Percentage gain in weight	266.0	267.4	311.0	346.7	343.5	265.8	295.2	291.5	278.3	328.1	305.1	301.2
Food proportions fed:												
Meat (percentage)[3]	17.1	16.8	25.7	23.7	24.4	26.9	28.8	26.3	16.2	25.9	17.1	100
Pellets (percentage)	82.9	83.2	74.3	76.3	75.6	73.1	71.2	73.7	83.8	74.1	82.9	..
Percentage of recorded loss	1.4	1.7	4.3	2.5	2.6	1.9	3.0	4.5	..[1]	4.0	..[1]	3.2
Percentage of unaccountable loss	12.3	11.9	4.6	9.5	1.1	5.9	15.1	2.1	..[1]	13.7	..[1]	2.0
Percentage of total mortality	13.7	13.6	8.9	12.0	3.7	7.8	18.4	6.6	..[1]	17.7	..[1]	5.2

[1]No data.
[2]Note sources of error in conversion rations in text.
[3]Raw beef liver.

pelleted diet and the control) to rainbow trout. Weight of food used in the calculations includes both pellets and meat.

The amount of food fed per day in terms of percentage of body weight was not adjusted after each weighing period. However, since the trout were growing at a steady rate the percentage of food fed per day, in relation to body weight, decreased progressively. This was continued throughout the experiment for all groups in an attempt to establish a definite daily food requirement for trout of a particular size and at a specific water temperature. This appeared to occur near the end of the sixth month of feeding when the amount of food fed per day was equal to 1.5 percent of total fish weight and at a water temperature of 42°F. At this time the average length was 6.4 inches (range, 3.0-10.1) and the average weight was 2.3 ounces.

The performance of all diets when presented graphically depicts a reduction in rate of gain during the last period similar to that shown in Figure 2.

Diets 2 and 6 produced greater gains than any of the other diets; Diets 3, 7 and 4 were next, in that order. The average rates of growth produced by Diets 1, 4 and 5 were less than that of Diet 8 (control).

The only known difference in the formulation of Diets 1 and 2 was the use of two different yeast products (Table 1). Diet 1 contained torula yeast, and Diet 2, brewers yeast. Diet 2 produced gains considerably higher than Diet 1. The similarity in the performance of Diets 3 and 4 indicates no differences between the two yeast when soybean oil meal was substituted for cottonseed meal. Diet 6, containing gelatin, resulted in a steadier rate of gain in weight of fish than did Diet 7 which contained a stabilized fat. Diet 5 produced a rate in gain of weight consistently lower than Diet 8 (the control).

TABLE 4.—*The results of statistical analysis for the difference in cumulative percentage gain in weight between groups fed pelleted diets and a control diet (No. 8) between groups fed pelleted diets*

Diets compared	Cumulative percentage gain[1]	Percentage loss or gain	Calculated "t" values[2]
1[3] and 8[4]	139.4—143.3	Diet 1, — 3.9	1.27
2[3] and 8	152.9—143.3	Diet 2, + 9.6	2.01
3[3] and 8	151.6—143.3	Diet 3, + 8.3	1.65
4[3] and 8	143.5—143.3	Diet 4, + 0.2	1.30
6 and 8	153.8—143.3	Diet 6, +10.5	1.96
1 and 2	139.4—152.9	Diet 1, —13.5	2.96**
3 and 4	151.6—143.5	Diet 3, + 8.1	1.22

[1]The percentage gain for each biweekly period was computed from the difference in weight at the beginning and end of the interval. The percentages for 14 biweekly periods were summed to obtain the values shown in this column.
[2]Tabular t05, 26 d.f. = 2.056* (significant); Tabular t01, 26 d.f. = 2.77** (highly significant).
[3]Replicated diets.
[4]Control diet was raw beef liver.

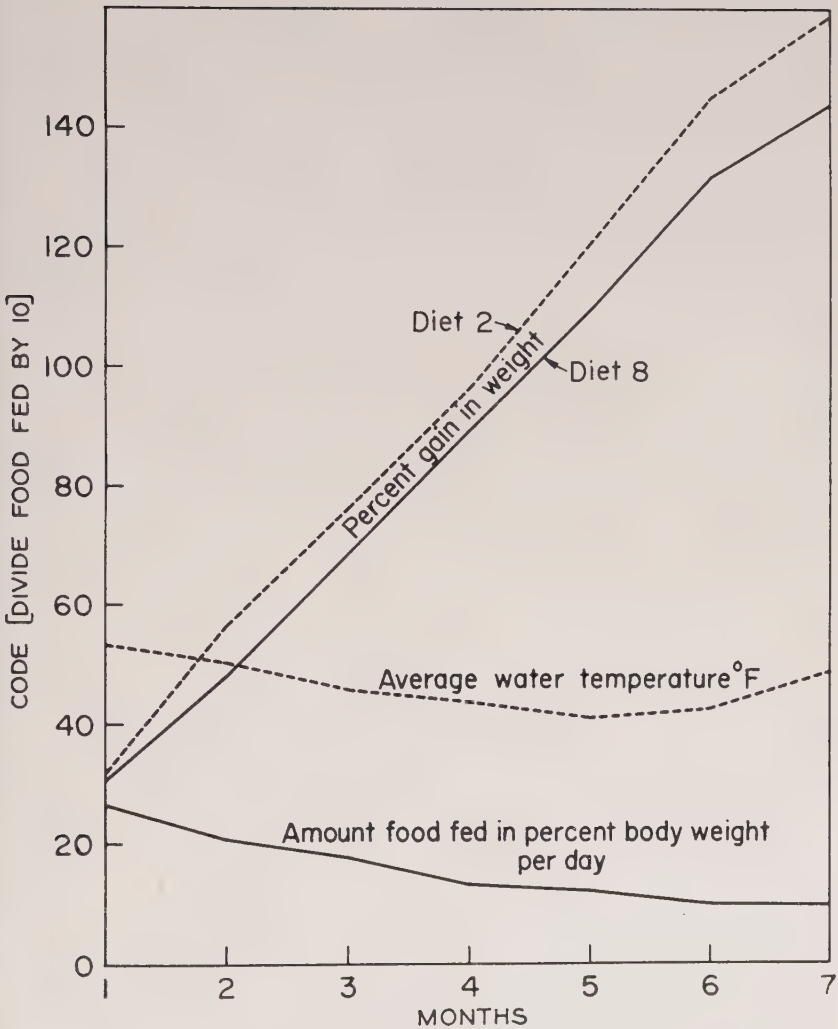

FIGURE 2.—Comparison of growth rates of rainbow trout fed different diets.

The results of statistical analysis (Table 4) for difference in percentage gain in weight (based on cumulative percentage gain per two-week period) between groups fed pelleted diets and a raw beef liver diet and between groups fed various pelleted diets showed a highly significant difference ($t = 2.96^{**}$ between Diets 1 and 2 and a difference approaching significance (calculated $t = 2.01$, tabular $t = 2.56^{*}$) between Diets 2 and 8 (the meat control). All other diets compared in Table 4 did not differ significantly.

In Michigan, it is the policy to plant hatchery trout shortly after they reach the legal length of seven inches. Thus many of the experiments were terminated when the majority of fish had reached this size.

Trout in each experimental lot were counted before, during, and at the end of the experiment, and counts were verified by a second person. Thus it was possible to evaluate diets in respect to numbers and length of fish as well as weight gained.

Among other factors, Table 3 presents the recorded loss and unaccountable loss. The recorded losses consisted of fish which died from jumping out of the tank and from handling during tank cleaning and weighing operations. No deaths were diagnosed as being caused by malnutrition.

It is difficult to determine specifically the reason for the extremely high and varied unaccountable loss. All experiments were conducted within a building, preventing losses by predators except trout. Since there was a considerable variation in length of fish in each group, it appears that cannibalism was a major factor in producing unaccountable losses. Grading each lot of fish to a uniform size at the beginning of the experiment would probably have prevented most of the cannibalism.

In several groups some factor other than difference in size could have caused a greater cannibalistic urge than in other groups. From the data presented in Tables 1 and 3, the evidence is inconclusive that one dietary constituent operated more than another to instigate cannibalism. Nevertheless, it appears probable that one or perhaps a combination of dietary factors in several of the diets influenced the natural cannibalistic instinct. It is believed that a dietary solution for this major problem can be found.

Results from the several diets varied with respect to production of legal-sized trout (seven inches and over), and with respect to mortality and condition factor. Diets 6, 8, 1 and 2 (in that order) produced the highest percentage of legal-sized fish; Diets 3 and 4, the lowest. Recorded losses in groups receiving Diet 1 were the lowest, and those receiving Diet 4, the highest. However, one group fed Diet 3 showed the lowest total loss of any group. When comparing Diet 8 with pelleted dry diets, the average length of large fish produced by the raw beef liver diet at the end of the six-month period was approximately one inch less than for those groups receiving pellets; at the end of the seven-month period, however, almost the same percentage of legal-sized trout were present as there were in the groups fed pellets. As expected, the condition factor of

TABLE 5.—*Summary of brook trout growth experiments (average water temperature, 40.8 F.).*

Feeding schedule[1]	Weeks	Cost per 100 pounds of food	Cost per pound of trout reared	Conversion	Percentage gain per 28 days
Group A					
Diet 1, 4 days/week					
Meat, 1 day/week	28	$7.00	$0.23	2.7	23.0
Group B					
Diet 1, 9 days/2 weeks					
Meat, 1 day/2 weeks	28	7.00	0.20	2.5	22.5
Group C					
Diet 1, 14 days/3 weeks					
Meat, 1 day/3 weeks	28	7.00	0.19	2.3	23.3
Yeast and meat control[2]	28	9.90	0.50	5.0	20.8

[1]No feeding on Saturdays and Sundays.
[2]Eight percent torula yeast and 92 percent raw beef liver, 5 days per week.

the rainbow trout in the control group (Diet 8) was somewhat higher than that of the others.

Brook Trout Feeding Experiment

This experiment was carried out on a production scale at the Marquette Hatchery, and was designed to serve a dual purpose. It was desired to know the performance of a pelleted diet when fed to brook trout, and, since a meat supplement was used periodically, it was designed to determine the length of time that could intervene between raw meat feedings. Four lots of 4,000 young-of-the year brook trout were placed in gravel-bottom raceways that were sufficiently large to compensate for normal growth during the experimental period without danger of overcrowding. Group A received Diet 1 four days per week and raw liver one day per week. Group B received Diet 1 nine days, and raw beef liver one day, every two weeks. Group C receivd Diet 1 fourteen days, and raw beef liver one day, every three weeks. A diet consisting of eight percent torula yeast and 92 percent beef liver was the control. This control was used because it was the usual practice at the hatchery to use this mixture for the regular hatchery diet. All fish in each group were weighed at the end of each month. The methods were similar to those previously described. The experiments were conducted over a 28-week period. The meat-control group received food equal to 3.6 percent of body weight per day and the other groups received amounts equal to 1.7 percent of body weight per day.

Table 5 shows the differences among the four groups in respect to conversion, average percentage gain at 28-day intervals, cost per pound of trout reared, and cost per hundred pounds of diet. The cost per pound of trout in the meat-fed control group was more than twice that of pellet-fed fish, and there was a lower percentage gain. Feeding of pelleted foods for a three-week period without a raw-meat supplement did not adversely affect growth rate.

Savings Due to Feeding Pelleted Dry Meals to Hatchery-Reared Trout

Michigan trout food Diet 1, was formulated and pelleted on a large scale in 1953. After several months of use at a number of Michigan hatcheries, the results were so favorable when compared to previous diets that it was adopted by the Michigan Department of Conservation as a standard production diet. Some state fish hatcheries were slow to adopt the pellet food on a production scale, but all are now feeding pellets.

After the pellet-feeding program started in 1953, fish food expenditures have decreased and number of pounds of trout planted have increased (Table 6). This is directly reflected in the cost per pound of fish produced.

TABLE 6.—*Production costs prior to, and following the start of pellet feeding*

Year	Cost of food	Pounds trout planted	Food cost per pound of trout	Calculated cost at 68c	Difference[2]
Prior to pellet feeding					
1951	$200,498	282,641	$0.71	..	..
1952	180,971	284,628	0.64	..	..
Pellet feeding program started					
1953	159,452	297,774	0.54	$202,486	$ 43,034
1954	141,736	390,613	0.36	265,617	123,881
1955	127,521	417,495	0.30	283,896	156,375
Total	$428,709	1,105,882	..	$751,999	$323,290
Other expenditures[1]	..	..	..	..	18,000
					$305,290

[1]Salary and expenses allotted investigator for formulating and testing dry pelleted diets during 3-year period.
[2]Calculated cost at 68 cents minus actual food cost.

Before the pellet-feeding program was adopted, it cost 68 cents for food to produce one pound of trout. During the three fiscal years of 1953-1956, when pellets were fed, Michigan hatcheries produced a total of 1,105,822 pounds of trout. The cost of food for this quantity of fish at the 68-cent rate would have been $751,999; but the actual cost of the pelleted food used was $428,709—a saving of $323,290 for the three-year period.

The indirect savings resulting from the use of pellets also constitute a major item. In addition to increase in average size already cited, more trout reached legal or planting size in the second year when fed pelleted food. This means fewer trout had to be carried over into the third year, making more pond space available for smaller fish.

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Mr. W. L. Cristanelli drafted the figures, and Misses Edith Burns and Ella Cerney assisted in preparation of the manuscript.

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FOOD CONSUMPTION AND GROWTH OF BROOK TROUT AT DIFFERENT TEMPERATURES

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Abstract

Food consumption (minnows) and weight gained by individual brook trout held at six temperatures within the range 3.5° to 21.0°C. are described relative to their body weight. The trout consumed most food and made best growth at 13°C. Utilization for growth of food consumed declined with increase in temperature.

Introduction

Lethal temperature limits for brook trout *(Salvelinus fontinalis)* have been found to be about 0° and 25.3°C. for fully acclimated fish by Fry *et al.* (1946). Graham[1] found that temperatures preferred by the brook trout are between 14° and 19°C. When acclimated to temperatures within this range they showed little selection and tended to remain at the same temperature. Capacity of trout to carry out activity, over and above maintenance requirements, was highest at 16°C. and the maximum cruising speed for this species was attained at temperatures between 16° and 20°C. (Graham, 1949). The present experiment was undertaken to investigate the gross effects of temperature on food consumption and growth rate.

There is ample evidence in the literature of the importance of temperature on the feeding and growth of trout. Titcomb (1920) drew attention to differences in the growth of trout in hatcheries supplied with water at different temperatures. The effect of temperature on the growth of groups of trout held under controlled conditions at hatcheries has been described by Haskell *et al.* (1956). Cooper (1953) observed a marked increase in the condition and growth rate of brook trout in several Michigan streams as the water temperature rose during April, May and June.

Investigators in Great Britain have studied in considerable detail the growth of brown trout. Pentelow (1939) showed that consumption of natural foods and growth rates of young brown trout increased with rising temperature up to 60°F. (15.6°C.) then fell off as the temperature increased. Wingfield (1940) noted a similar increase from 3.2° to 15.4°C. Brown (1946) found that the growth rates of brown trout were high between 7° and 9° and between 16° and 19°C. The two maxima

[1]Master's thesis. University of Toronto, 1948.

were explained by the differential effect of temperature on food consumption and the utilization of this food for growth. Swift (1955) studying the relation between growth and thyroid activity, obtained similar optima during the natural temperature cycle. The greater activity of the trout and of the thyroid during mid-summer suggests that maintenance demands on the metabolites were relatively high at that season.

Sullivan (1954) found that the spontaneous activity of brook trout increased with temperature then decreased only to rise again at temperatures above the preferred temperature. This response according to Fry (in press) explains the temporary leveling off in the otherwise steady increase of routine metabolism with temperature noted for brook trout by Job (1955). This leveling is not pronounced in brook trout and does not permit much increased scope for growth. It may, however, be of sufficient magnitude in brown trout to account for the two temperature optima for growth.

Methods

The study of the growth of a group of fish in a confined space must eventually take into account interference caused by competition for position as well as food. In order to avoid this single fish were held in separate tanks. Four yearling speckled trout ranging in weight from 31 to 91 grams were placed in four circular tanks 24 inches in diameter in which the water was maintained within one degree of 9, 13, 17 and 21°C. After four weeks at one temperature each trout was transferred to the next highest or lowest temperature depending on whether it was ascending or descending the temperature series. After reaching and spending four weeks at 21°C. three fish were passed down the series to 9°C. again. The fourth fish developed 'fin rot' at 21°C. and was withdrawn from the experiment. Two additional trout were introduced into the experiment later and held at 9°C. When refrigerated water became available two more fish were held at 3.5° and 7.6°C.

Dissolved oxygen in the tanks varied from 70 to 100 percent saturation.

The trout were fed live minnows; *Chrosomus eos, Semotilus atromaculatus,* and *Notropis cornutus.* These were added to the tanks daily in sufficient numbers so that the supply was rarely exhausted. The minnows placed in the tank and those remaining at the end of the week were weighed. The trout were weighed at the end of each week. At 3.5° and 7.6°C. minnows were occasionally only partly consumed. Collection of fragments was probably incomplete and thus some error was introduced into the calculation of the live weight of minnows ingested.

The weight of minnows not immediately eaten by the trout was probably somewhat less than their weight when placed in the tank. Samples of minnows were therefore held for a week at the various temperatures used in the experiment to discover the order of magnitude of the weight

loss. This loss did not exceed 11 percent for the full week. The error introduced into the food consumption data would therefore be somewhat less than this figure and no correction has been made for it.

Food Consumption and Weight Gained

As the experiment proceeded it became evident that after transfer to each new temperature, from three to six days frequently elapsed before the trout fed normally. Therefore data recorded during the first week were disregarded. For the remaining three weeks at each temperature the weight of the food consumed by each fish each week was determined. Food consumed was expressed as percentage of the body weight of each fish at the beginning of each week of the experiment. Values thus ob-

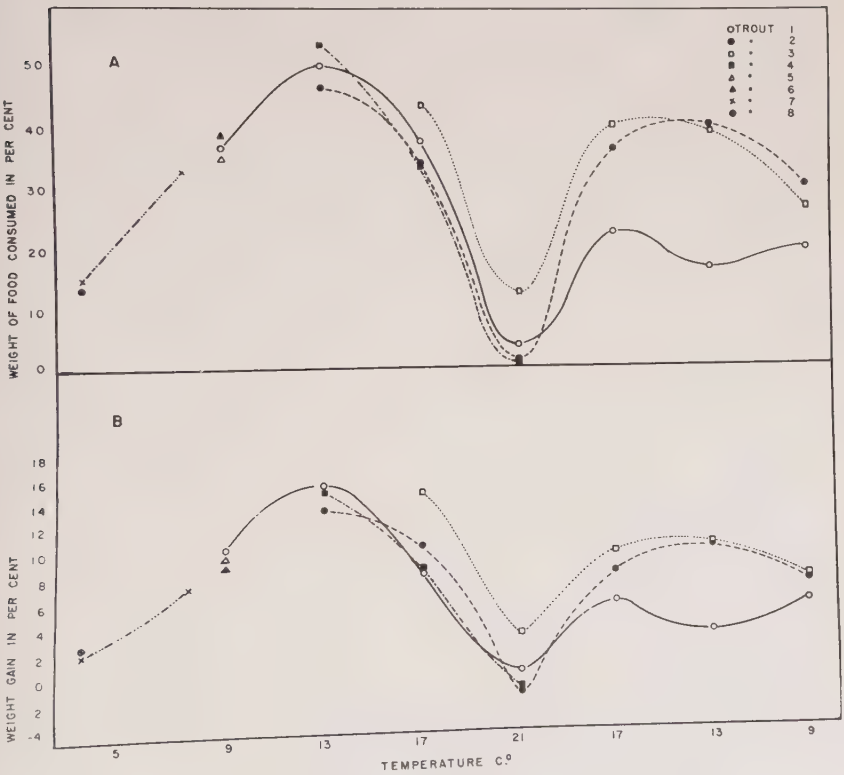

FIGURE 1.—The average weekly food consumption and weight gain of brook trout at different temperatures expressed as a percentage of initial weekly weights.

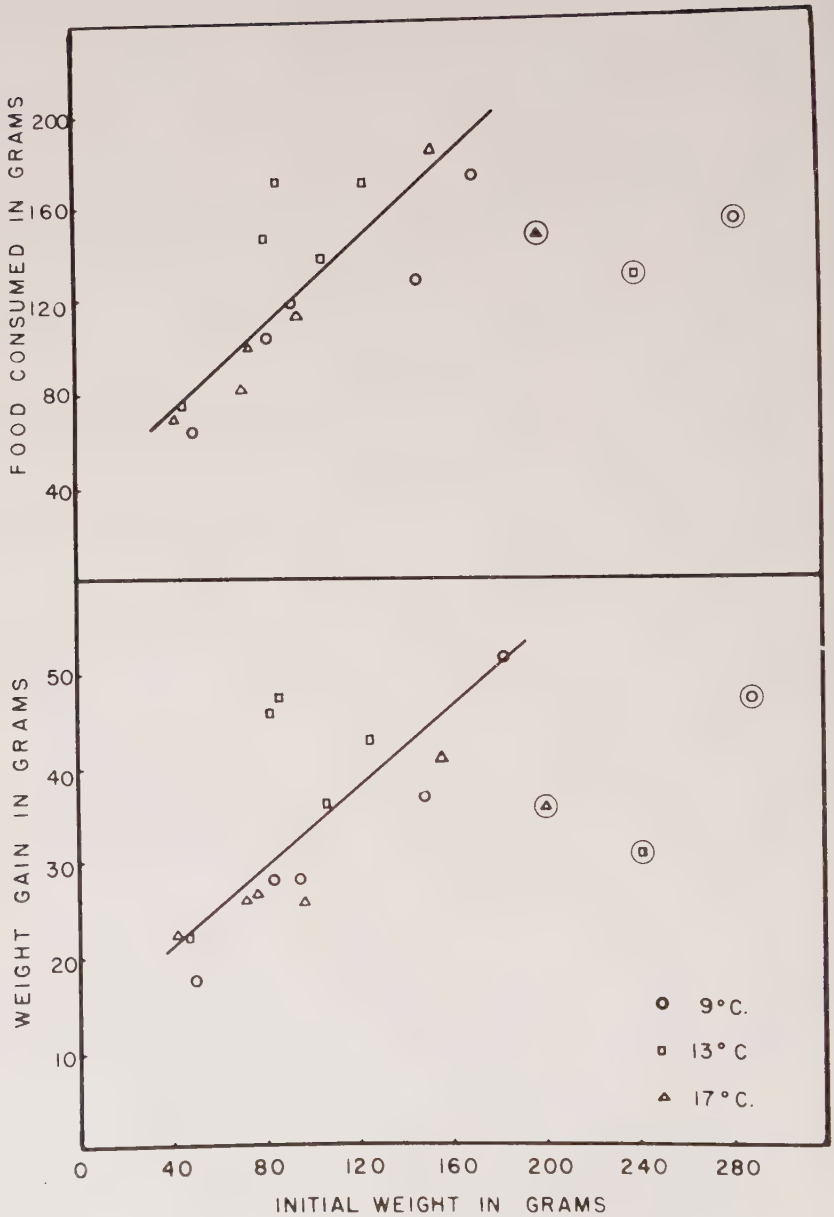

FIGURE 2.—Relationship of food consumed and weight gained to the initial weekly weight of brook trout held for three week periods at 9, 13 and 17°C. Points encircled have been disregarded in obtaining regressions.

tained for the three weeks at each temperature were averaged for each fish and are plotted in Figure 1A.

The weekly consumption of minnows by the trout about doubled for each 4°C. rise in temperature until at 13°C. about 50 percent of the body weight was consumed weekly. At 17°C. feeding decreased and at 21°C. it was only about six percent of body weight. Feeding increased when the trout were moved from 21° to 17°C. again but changed little when they were moved to 13°C. This slow response may have been due to the slower acclimation rate to lower temperatures. At 9°C. two of the three fish reduced their food consumption. The third fish (No. 1) fed considerably less than others during the latter part of the experiment and there is some reason to believe that it was unable to feed effectively in the small tanks because of its large size.

Weight gain was obtained for each fish and expressed as a percentage of the initial weight for each of the three weeks following the first week after introduction to a new temperature. Means for the three weeks at each temperature are plotted in Figure 1B and the curve drawn from them closely parallels that for food consumed.

In order to ascertain if the use of trout of different sizes had any effect on food consumed and weight gained, the data for all fish held at 9, 13 and 17°C. have been plotted in Figure 2. If the values for fish No. 1 after it reached 21°C. are omitted for the reason mentioned previously, the relationship between food consumed and initial weight and between weight gain and initial weight can be described by straight lines with correlation coefficents of 0.907 and 0.853 respectively, thus showing the same close order of relationship for the two measurements on fish of different sizes.

When these data were analysed by the covariance method described by Snedecor (1956) the variability in food intake and weight gained was not entirely explained by the differences in initial weights of the fish. Much of the residual variability was attributable to the different temperatures at which the fish were held. Values for the variance ratios F were 6.37 for food consumed and 5.56 for weight gained ($F_{.05} = 3.98$ and $F_{.01} = 7.20$). The effect of temperature was highly significant.

When mean weight of food consumed and mean weight gained during each three week period at the temperatures 9, 13 and 17°C. are expressed in terms of a mean initial weight of 96.7 grams, it is found that food consumed was high at 13°C. (145.7 grams), low at 9°C. (105.4 grams) and intermediate at 17°C. (116.9 grams). Weight gain was also high at 13°C. (40.1 grams), low at 9°C. (29.6 grams) but nearly the same at 17°C. (29.8 grams). The ratio of weight gain to food consumed showed a decrease with rising temperature, being 0.281 at 9°C., 0.275 at 13°C. and 0.255 at 17°C. This is what might be expected with increasing demands on metabolites to meet maintenance requirements at higher temperatures.

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THE EFFECTS OF LIME APPLICATION TO ACID BOG LAKES IN NORTHERN MICHIGAN[1]

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ABSTRACT

To investigate the observed correlation between alkalinity and productivity of lake waters and to test the use of lime in bog lakes to increase biological productivity, lime application was made to two, acid, soft-water, colored bog lakes in the upper peninsula of Michigan. Lime application was made twice to each of the two lakes, once in the summer under thermally stratified conditions and once in the autumn under nearly homothermous conditions, by pumping a lime-water mixture into the surface waters. Total rate of lime application was 100 pounds per acre-foot in each lake.

The summer lime applications resulted in raising the pH and increasing alkalinity, total hardness and conductivity in the epilimnion only. The autumn application resulted in similar effects in the lower hypolimnion, because of sinking of the denser lime solution to the bottom where because of its greater density it did not later mix with upper layers.

Lime application did not decrease the organic colloidal color.

Total phosphorus was greatly increased in the bottom waters of one treated lake which originally was low in total phosphorus but there was no significant increase in the bottom waters of the other treated lake where total phosphorus concentrations were originally high. Total phosphorus also increased temporarily in the epilimnion of one lake following the summer application.

A bloom of nannoplankton *(Microcystis aeruginosa)* was observed in one lake following the release of epilimnial phosphorus. Chemical data indicated that because of the presence of higher bicarbonate concentrations, the nannoplankton utilized carbon dioxide at a rate which may not have been possible without lime application. In both lakes the following summer, significantly higher standing crops of net phytoplankton were observed (principally of *Dinobryon sertularia)*. Increases in standing crop of zooplankton also occurred the year following lime application.

INTRODUCTION

A direct correlation between the biological productivity and alkalinity of lake waters has been observed and reported frequently (Ball, 1948; Moyle, 1949; and others). This correlation appears to hold generally true at the lower region of the range of alkalinity found in natural waters (lakes with soft to medium hardness), but at extremely high values of alkalinity the correlation appears to be reversed with the result of "alkali-

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trophy" in hard-water lakes (Barrett, 1953).

In the upper peninsula of Michigan, despite the presence of calcareous glacial drift, many seepage lakes including colored bog lakes, fall into the lower part of the alkalinity range; measurements reveal many waters of less than 5 p.p.m. total alkalinity. These lakes, for the most part, are characteristically of low productivity, as revealed by a paucity of plankton and bottom fauna, a scarcity of aquatic vegetation, and the slow growth of fish.

The purpose of the present experimental program was to test the feasibility of increasing the biological productivity of these waters by increasing the alkalinity through the application of hydrated lime. In Michigan the first attempt to alkalinize an acid lake was in 1943, when a small application of hydrated lime was made to a soft-water, non-bog lake by the Michigan Department of Conservation; the same lake was treated again in 1945, this time with crushed limestone,[2] but neither treatment effected any significant change in alkalinity. In 1952, the same lake again was incorporated in an experimental alkalinization program which continued through 1955 (Ms. in preparation). The use of lime in treating bog lakes was investigated in Wisconsin in 1948 by Hasler, Brynildson and Helm (1951). They offered several suggestions as to the mechanisms by which productivity might be increased by lime application in colored bog lakes. The color—caused by humic colloids—would be flocculated and precipitated through combination with calcium, thus permitting deeper light penetration and increasing the volume of the trophogenic zone. Secondly, alkalinization of the water would mobilize nutrients which are fixed in unavailable organic forms in the lake soils. Finally, a higher concentration of bicarbonates would result, offering available carbon dioxide to plants for photosynthesis in high concentration. Following their experiment, they reported that the lime treatment resulted in clearing the color from the water and improving oxygen conditions for trout in the deeper, cooler levels of the lakes, but showed no striking differences in nutrient content of the water. It was later reported (Johnson and Hasler, 1954) that no apparent increase in production or carrying capacity resulted.

In the summer of 1953 the present research program was initiated upon two bog lakes in the upper peninsula of Michigan. Three postulates were made regarding the mechanisms by which biological productivity might be increased by the use of lime, and the sampling program was designed to test these postulates: (1) a greater concentration of bicarbonate alkalinity, offering more available carbon dioxide for photosynthesis, would result; (2) phosphorus would be released either by increased decomposition activities or through ion-exchange phenomena in the mud; and (3) the colloidal organic color would be decreased by flocculation and precipitation caused by combination with calcium.

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[2]Report on Stoner Lake, Alger-Delta County, Michigan by R. C. Ball, 1947. Unpublished report.

The two bog lakes used in the experiment, Timijon and Starvation lakes, are both located in the Hiawatha National Forest, an area which contains many small bog lakes of the colored, acid, soft-water type. Timijon Lake, T. 44 N., R. 18 W., Sec 19, Schoolcraft County, was 2.0 acres in surface area with a maximum depth of 42 feet, and Starvation Lake, T. 44 N., R. 19 W., Sec. 1, Alger County, was 1.7 acres in surface area with a maximum depth of 42 feet. Each lake was completely surrounded by an encroaching sphagnum-leatherleaf bog mat; the waters were acid (approximately pH 5), very soft (3 to 5 p.p.m. total hardness), and colored by humic colloids. The bottom types in both lakes were of brown fibrous peat near the mat and of a fine, gelatinous pulpy peat in the deepest regions of the lakes. Both lakes appeared to be meromictic.

Methods Of Lake Sampling And Lime Application

A periodical sampling program was initiated in the summer of 1953 consisting of the chemical analysis of the water and the collection of two net plankton samples, at approximately ten-day intervals, from each of the following four levels: central epilimnion (always at a depth of three feet), top of thermocline, central hypolimnion, and bottom waters (one foot above the mud-water interface). Chemical analysis consisted of the determination of dissolved oxygen, free carbon dioxide, pH, alkalinity, total hardness, conductivity, color, and total phosphorus. Air and water temperatures, weather data and light penetration (Secchi disk) were also recorded. The plankton from a ten-liter sample was collected with a Juday plankton trap and analyzed volumetrically by counting the organisms under a microscope in a Sedgewick-Rafter cell and determining average volumes of each species by measuring with a calibrated ocular micrometer.

Lime applications were made twice to each lake during 1954, the first during the summer under conditions of thermal stratification and the second in the fall when the lake waters were nearly homothermous. For all applications, a raft-and-pump system was employed which mixed the lime with water and discharged the mixture into the surface waters. The apparatus consisted of a raft ten feet long and six feet wide, supported in back by the edge of the bog mat and in front by two floating 50-gallon drums. A plywood mixing tank was lowered through a rectanglar hole in the raft. This allowed the intake of water at the bottom of the front side of the tank. A hopper was constructed at the top of the mixing tank through which the lime was introduced. The intake hose of the pump was placed in the mixing tank, where both lime and water were taken up, carried through the mechanism of the pump and through the exhaust hose of the pump, to be finally discharged into the lake (Figure 1.) A total rate of application of 100 pounds hydrated lime per acre-foot was applied in this manner to each of the two lakes, half this amount being applied at each of the summer and fall applications. The summer applica-

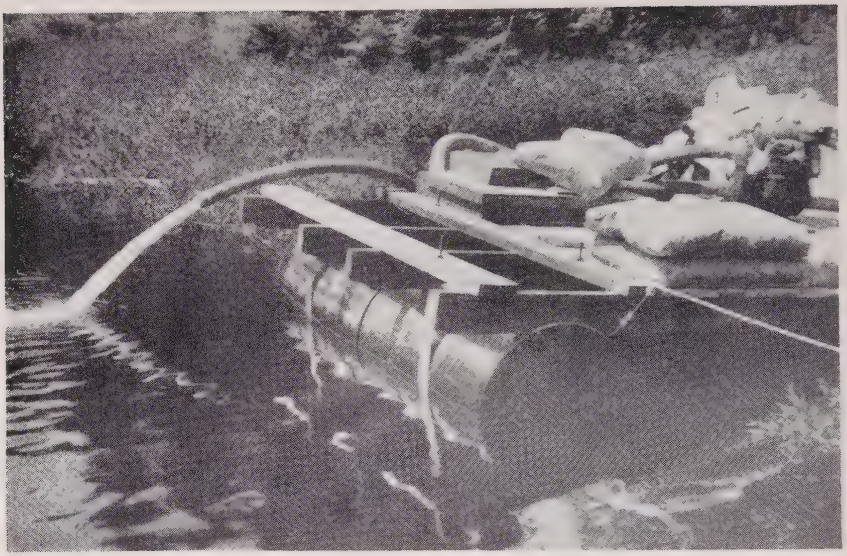

FIGURE 1.—Summer lime application to Starvation Lake, showing raft-and-pump system.

tion in Starvation Lake was made as rapidly as possible, but because apparent destruction of the plankton resulted from the precipitous chemical changes, the subsequent summer application to Timijon Lake was made at a more gradual rate through most of the summer. The discharge point for the summer application to both lakes was immediately in front of the raft. Both fall applications were made rapidly, with the discharge point near the center of the lake.

IMMEDIATE EFFECTS OF LIME APPLICATION

Because of the strong thermal stratification present during the summer applications, the immediate effects of the lime were apparent only in the epilimnion and no chemical changes were observed below the thermocline. The chemical effects in the epilimnion, however, were abrupt and marked. Figure 2 shows the changes in pH and alkalinity in the central epilimnion of Starvation Lake, where the application was made rapidly, while Figure 3 shows the pH and alkalinity in the central epilimnion of Timijon Lake where lime applications were made throughout the summer.

At the fall application when the lake waters were nearly homothermous, almost the entire application of lime fell to the bottom, apparently because of the greater density of the lime solution. There was little mixing of the lime in the upper levels of the lakes. Because of the meromictic char-

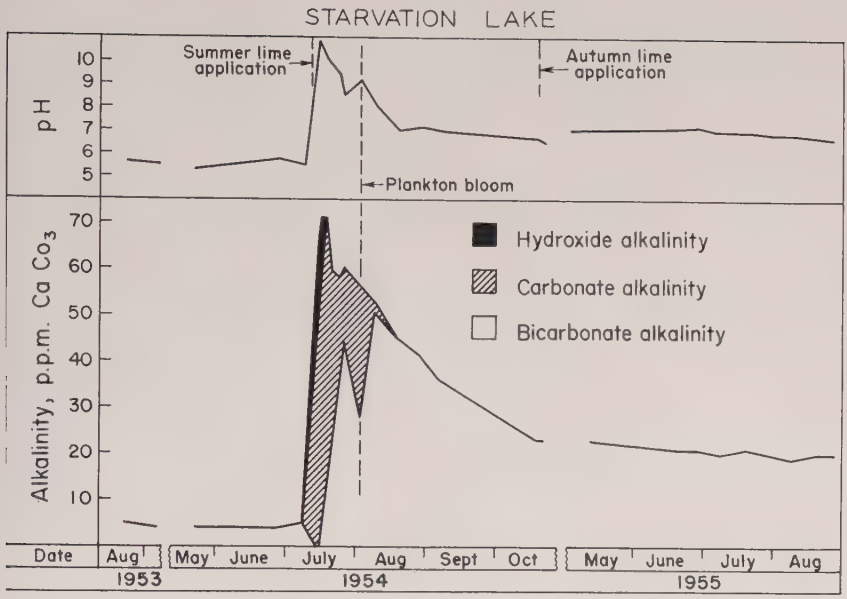

FIGURE 2.—pH and alkalinity in the central epilimnion, Starvation Lake.

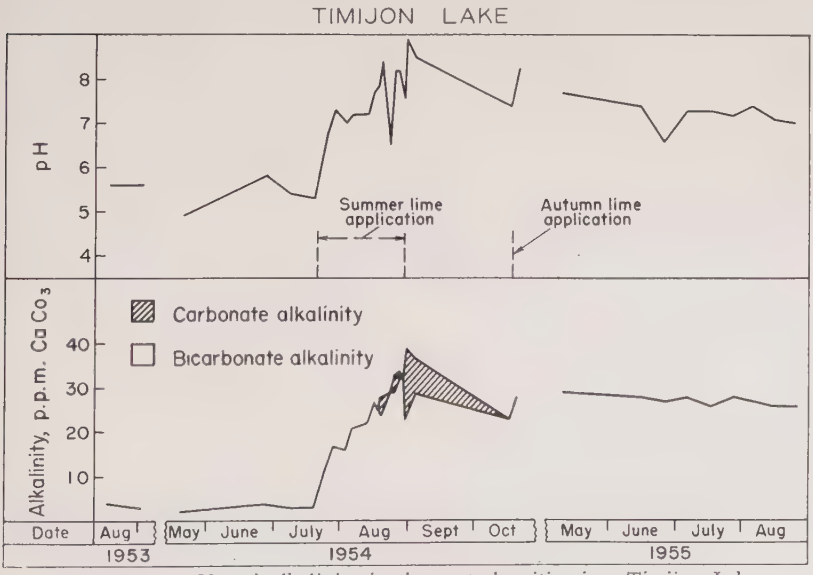

FIGURE 3.—pH and alkalinity in the central epilimnion, Timijon Lake.

acter of the lakes the lime solution remained at the bottom and did not later circulate through the upper levels. In the bottom waters of Starvation Lake, the pH rose from about 6 to 11, while total alkalinity increased from 17 to 128 p.p.m. In Timijon Lake, at the same level, pH values also rose from about 6 to 11, and total alkalinity increased from 13 to 175 p.p.m.

Changes in total hardness and conductivity, in both the epilimnion and hypolimnion, in both lakes, generally followed those of total alkalinity. No decrease in color was observed following the lime applications in either lake.

Release of Phosphorus from Lake Soils

Preliminary Laboratory Experiments

To obtain some information upon the possibility of a release of phosphorus from the lake soils upon lime application, the following experiments were caried out in the laboratory prior to the field experiments involving lime application to the lake. The general pattern of these experiments was to add hydrated lime at known rates of application to bottles containing water and mud from the lakes and subsequently to analyze the water for dissolved phosphorus. Three mud-water combinations from each of the two bog lakes were treated with lime: (1) surface water with mud, (2) bottom water with mud, and (3) surface water without mud (control). Six different rates of lime application were used: 0 (control), 25, 50, 100, 150, and 200 pounds per acre-foot. The experimental unit consisted of a two-quart jar containing 50 mililiters of mud, taken from the mud-water interface, and one liter of water. The lime was added by dissolving weighed amounts of lime with water from the experimental bottles and adding the solution to the bottle. Water samples were extracted for analysis by pipette three days after the lime addition.

The results are shown in Figure 4, where it can be seen that dissolved phosphorus concentrations were higher at the higher rates of lime application; this was true in all series containing mud except that series including Starvation Lake bottom water, where the dissolved phosphorus concentration was originally high. In both control series (no mud) there were no increases in dissolved phosphorus concentrations with lime application, indicating that the higher phosphorus concentrations observed in the other series resulted from the presence of mud.

Field Experiments

Immediately following the rapid lime application during the summer in Starvation Lake total phosphorus increased from approximately 15 p.p.b. before application to a high of about 70 p.p.b. in the central epilimnion, as shown in Figure 5. A similar increase to about 60 p.p.b. occurred at the top of the thermocline level. The high values decreased soon after

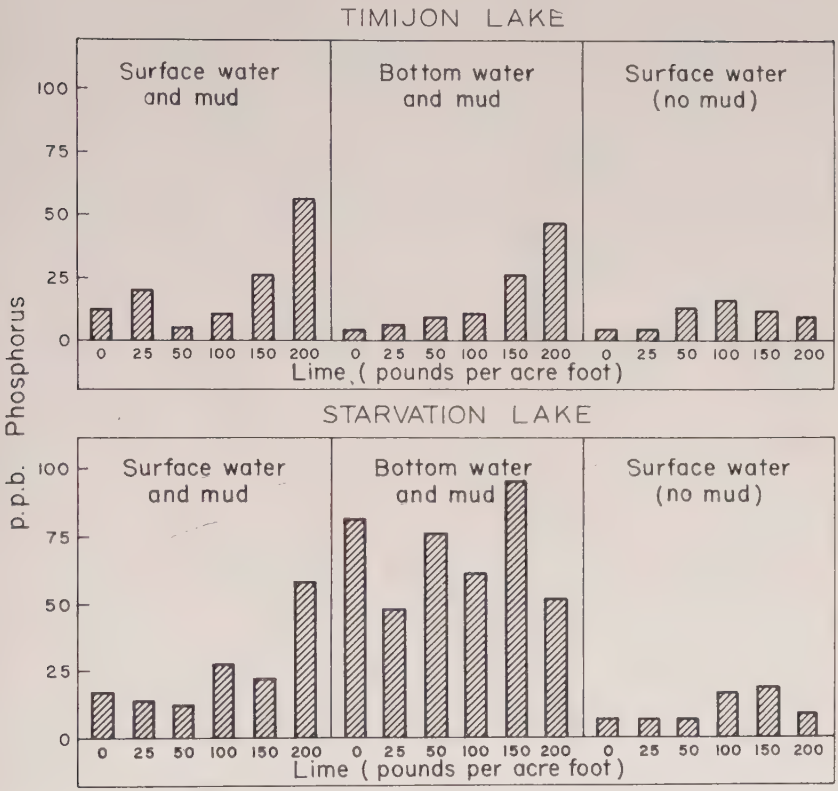

FIGURE 4.—Dissolved phosphorus in experimental bottles of lake water and mud treated with lime.

to values near those existing before lime application. It is suggested that the source of released phosphorus was in the bottom mud in those shallower areas of the lake where epilimnial waters, originally containing low concentrations of phosphorus, came into contact with the bottom. These conditions are essentially those produced in the bottle experiments with "mud and surface water," where the release of dissolved phosphorus was observed. (The possibility of the increased phosphorus being due to its presence in the liming material was eliminated after analysis of the lime showed no significant amounts of soluble phosphorus.) In Timijon Lake, where the summer lime application was made gradually through the summer, no significant increases in total phosphorus were observed in the epilimnion.

Following the fall lime application to Timijon Lake, which fell almost entirely to the bottom, a large increase in total phosphorus was observed

in the bottom waters. This increase was from a mean of 23 p.p.b. before the fall application (1954) to a mean of 156 p.p.b. after the fall application (1955); a t-test showed the difference to be highly significant. This result was essentially the same as obtained in the laboratory bottle experiments with "mud and bottom water," where the release of dissolved phosphorus was observed. In Starvation Lake, where the bottom waters originally contained high concentrations of total phosphorus, no significant increase in total phosphorus occurred following the fall application; this result was similar to that observed in the bottle experiments with Starvation Lake "bottom water and mud."

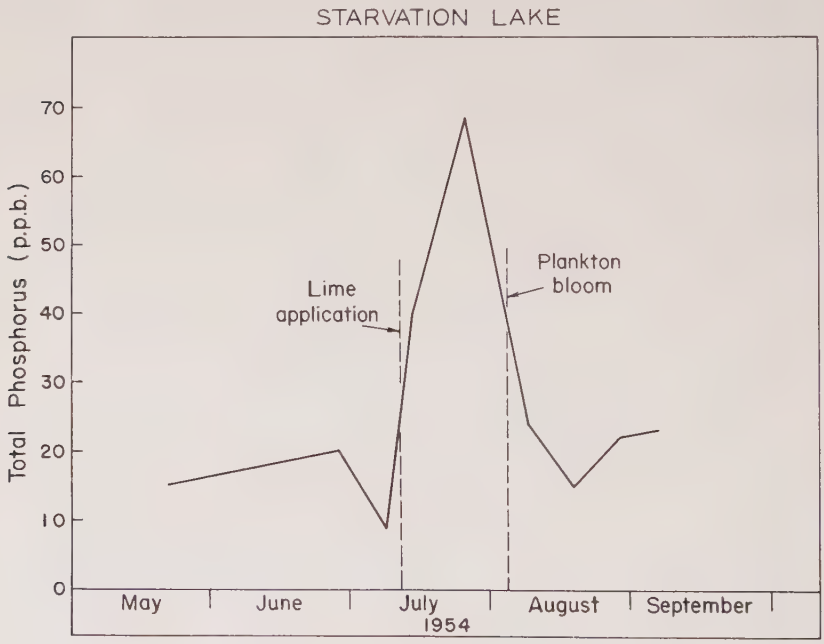

FIGURE 5.—Total phosphorus in central epilimnion, Starvation Lake, 1954.

The release of phosphorus upon alkalinization may be accomplished by one or both of two mechanisms. The first is by mineralization of organic phosphorus through decomposition. Acid conditions, such as are found in bog lake waters and muds, have inhibitory effects upon the micro-organisms responsible for decomposition of organic matter and the subsequent mineralization of nutrients. It is well established that the addition of liming materials, where such acid conditions exist in soils, improves conditions for decomposition by micro-organisms and, therefore, hastens decomposition (for general discussion see Lyon, Buckman, and Brady, 1953, p. 139, and

Waksman, 1938, p. 349). Secondly, phosphate ions may be released through anion exchange; in the case of the addition of lime, an anion exchange between phosphate and the introduced hydroxide radicals is probably the reaction involved. Anion exchange involving phosphorus in soils may concern phosphate adsorbed to clay minerals, organic colloids, and hydrated aluminum and iron oxides. It is not likely that clay minerals will be found in a bog lake, so the sources of exchangeable phosphate are most likely to be colloidal hydroxides and organic matter. In a general discussion of anion exchange in soils, Wiklander (1955) describes anion exchange mechanisms in clay minerals and hydrous oxides, and says, "Humic acids take part in anion exchange, as evidenced by their power of releasing adsorbed phosphate, but the exact mechanism is not known." Where releases of phosphorus were observed in the present study no data were collected to suggest which of the above two mechanisms, i.e., increased decomposition or anion exchange, were in operation.

From the practical standpoint, the release of phosphorus due to increased decomposition would have greater importance than that due to anionic exchange. In the former mechanism, the source of phosphorus to be mineralized is in almost inexhaustible supply and might be incorporated in a more balanced organic matter cycle, while in the latter mechanism, the supply of exchangeable adsorbed phosphate ions may soon become exhausted, a phenomenon which has been observed in the use of lime to release nutrients in European carp ponds (Neess, 1949).

The value of applying lime to increase phosphorus concentrations in hypolimnial waters, such as occurred in Timijon Lake, when such waters appear never to enter into circulation with upper waters, may be questioned when such methods are applied in lake management. The bottom water of Starvation Lake contained original high concentrations of phosphorus; yet biological productivity in this lake (as measured by standing crop of plankton) was no greater than in other bog lakes lacking such high concentrations of phosphorus in the hypolimnion. Such phosphorus release can probably best be utilized in lakes which stratify yet still are holomictic; in these lakes phosphorus, released in the hypolimnion under deoxygenated conditions during the summer stratification period, would be transported to the upper trophogenic zone during fall and spring circulation periods.

Effects of Alkalinization upon Plankton Production

The immediate effects of the rapid summer lime application to Starvation Lake apparently resulted in a partial destruction of the plankton. The subsequent lime application to Timijon Lake was made gradually throughout the summer; however, the gradual application also appeared to destroy much of the plankton. Whipple (1948, p 405) discusses the use of hydrated lime as an algicide and says that lethal effects are probably due

to the loss of carbon dioxide available for photosynthesis or to changes in hydrogen ion concentration.

In Starvation Lake, after the pH in the central epilimnion had decreased from its high of near pH 11 following the summer lime application to about pH 8 (the point near which free carbon dioxide should appear), a definite plankton bloom of *Microcystis aeruginosa* Kuetz. was observed. This organism is a member of the Cyanophyta (blue-green algae); it was not observed prior to lime application nor were any other members of the blue-green group ever observed in either lake. The bloom did not appear among the quantitative data secured from the plankton samples collected because the organism was apparently too small to be retained by the plankton net (silk bolting cloth No. 20). The bloom was, however, obvious to the eye; it gave a definite green color to the water and collected in windrows of "scum" along the lee shores of the lake at the edge of the bog mat. The date when it was most strikingly observed was August

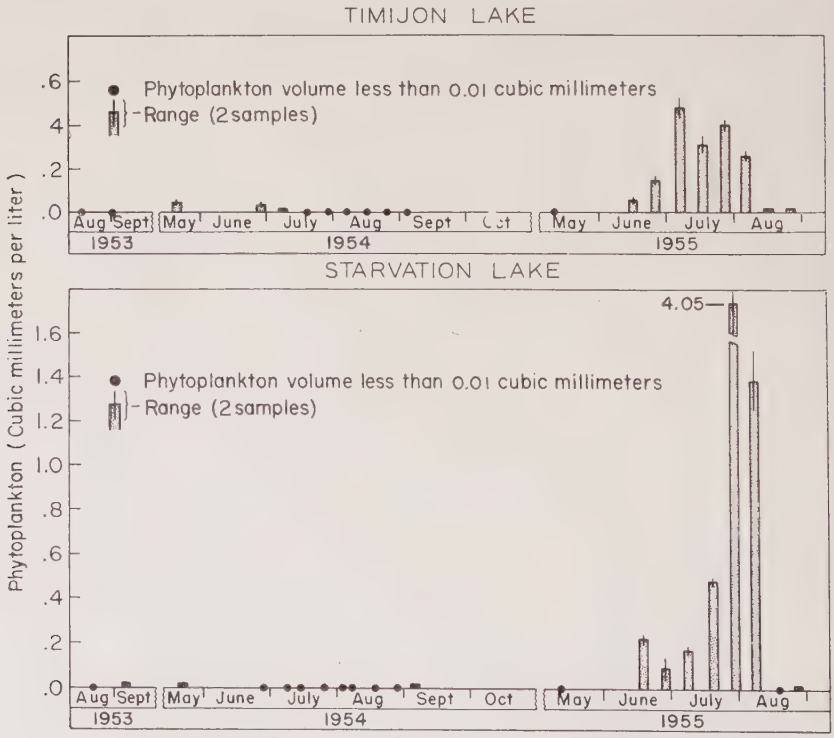

FIGURE 6.—Average volume of net phytoplankton in cubic millimeters per liter in central epilimnion, Timijon and Starvation lakes. Lime was applied in the summer and fall of 1954.

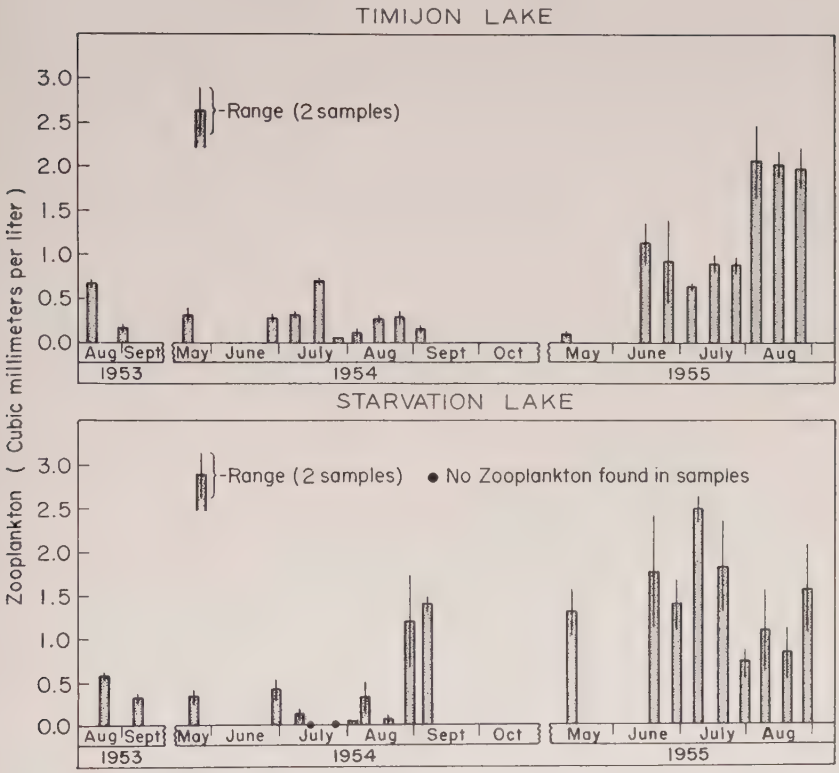

FIGURE 7.—Average volume of zooplankton in central epilimnion, Starvation and Timijon lakes. Lime was applied in the summer and fall of 1954.

2, 1954, and chemical data for this same date reflected the effects of the bloom. Dissolved oxygen increased markedly from the previous sampling date, from 2.8 to 10.5 p.p.m.; a rise in pH was observed with a corresponding shift in the form of alkalinity from the bicarbonate form to the normal carbonate form, these being the results of carbon dioxide extraction from the bicarbonates (see Figure 2). The Secchi disk reading was decreased markedly. The bloom occurred while the phosphorus content of the epilimnion was high (after the release of phosphorus in the epilimnion) which decreased after the beginning of the bloom (see Figure 5).

During the summer of the following year (1955) the standing crops of both phytoplankton and zooplankton were observed to reach much higher levels than before lime application in both lakes, as shown in Figures 6 and 7. The principal organism in these large standing crops of net phytoplankton in both lakes was *Dinobryon sertularia* Ehrenberg,

a member of the Chrysophyta (yellow-green algae) which had not been observed in either lake prior to lime application. There were no changes in pH or in the form of alkalinity attributed to these large standing crops of phytoplankton in 1955, giving no indication of carbon dioxide extraction from the bicarbonates. Figures 6 and 7 exclude data concerning one species of algae, *Peridinium limbatum* (Stokes) Lemmermann; this organism was omitted from the net plankton volume analyses because of the extreme variation it caused as a result of its relatively large size and scattered occurrence in the cell counts.

In considering the question of whether a causal relationship exists between alkalinity and productivity, differentiation should be clearly made between fertilization and lime application. In the former, the effects are principally direct ones; i.e., nutrients are supplied to the lake waters which are utilized directly by producing plants. The latter procedure is more a case of chemical modification and the effects are principally indirect: (1) nutrient availability is improved due to more optimum reactions (pH) and ion concentrations, and (2) a greater concentration of immediately available carbon dioxide results.

The events which occurred in Starvation Lake in 1954 soon after the summer lime application provided the necessary data to calculate the rate of carbon dioxide production by the lake and also the rate of its utilization under conditions of a plankton bloom, for the central epilimnion level. In Figure 2, the graph for bicarbonate alkalinity shows a linear increase between the dates of July 15, 1954, and July 25, 1954, covering a period of 10 days which included five sampling dates; during this period the bicarbonate concentration was increasing due to the reaction of normal carbonates with the carbon dioxide which was produced by the lake's respiratory activities (respiration, decomposition, and atmospheric absorption). The slope of the graph represents the rate of increase of bicarbonate, and, proportionally, the rate of carbon dioxide production. This rate, calculated by means of ratios of molecular weights of the compounds involved, was 1.94 p.p.m. carbon dioxide per day.

On August 2, 1954, the phytoplankton bloom of *Microcystis aeruginosa* was observed. Since carbon dioxide was extracted from the bicarbonates, it can be concluded that for the eight-day period from July 25 to August 2, or for an unknown shorter period of time, the phytoplankton utilized carbon dioxide at a rate more rapid than the rate of supply from the lake's respiratory activities. Table 1 shows the "balance sheet" for carbon dioxide for the eight-day period of plankton bloom. Section A is the carbon dioxide available over the eight-day period, being equal to the sum of that present at the beginning of the eight-day period plus the carbon dioxide production for the eight days, or a total of 34.9 p.p.m. carbon dioxide. The carbon dioxide utilized by the phytoplankton over the eight-day period, Section B, is equal to that available (Section A) minus that remaining at the end of the period, or 22.6 p.p.m. carbon

TABLE 1.—*Carbon dioxide utilized by phytoplankton after lime application compared to carbon dioxide available without lime application, Starvation Lake (as p.p.m. carbon dioxide).*

A. CO_2 available over 8-day period		34.9
Present at beginning of period,		
Free CO_2	0.0	
Half-bound CO_2 (bicarbonate)	19.4	
Production in 8-day period	15.5	
	34.9	
B. CO_2 utilized over 8-day period		22.6
Available over period (Section A)	34.9	
Less CO_2 present at end of period,		
Free CO_2	0.0	
Half-bound CO_2 (bicarbonate)	12.3	
	22.6	
C. CO_2 available without lime application		20.3
Present at beginning of period,		
Free CO_2	3.0	
Half-bound CO_2	1.8	
Production in 8-day period	15.5	
	20.3	
D. Portion of CO_2 utilized that was result of lime		2.3
CO_2 utilized (Section B)	22.6	
Less CO_2 available without lime application (Section C)	20.3	
	2.3	

dioxide. In Section C, the carbon dioxide available under conditions of no lime application is calculated to be 20.3 p.p.m. carbon dioxide, using the production rate computed above and the free carbon dioxide and bicarbonate concentrations found before lime application. The portion of that carbon dioxide utilized which was the result of lime application (i.e., the difference between the carbon dioxide utilized during the eight-day period and that which would have been available without lime application) is calculated in Section D. It is one measure of the effect of lime application upon phytoplankton production. It should be pointed out that it would not be necessary to know the carbon dioxide production rate in order to calculate the figure in Section D, for it would cancel out in the final substraction.

In making the above calculations several assumptions were necessary; they were: (1) the carbon dioxide production observed for the 10-day period of increasing bicarbonate concentration (July 15 to July 25) was not higher, due to a more alkaline reaction and increased decomposition,

than for a similar period of time without lime application; (2) there occurred no loss of carbon dioxide to the atmosphere during the 10-day period nor during the 8-day period of the plankton bloom (which is probably a valid assumption since normal carbonates were available during both periods for combination with carbon dioxide); (3) the increased standing crop of phytoplankton did not raise the rate of carbon dioxide production because of the algae's respiration, and (4) the period of plankton production and intense carbon dioxide utilization was not less than eight days. If any of the above assumptions were invalid, the figure calculated in Section D would either be greater or remain the same; the figure calculated, then, is a *minimum value.* Furthermore, it would not be expected that the phytoplankton would extract the carbon dioxide from all bicarbonate present; in the eight-day period of plankton bloom, 65 percent of the available carbon dioxide was utilized. If, in Section D of the table, 65 percent of the carbon dioxide available under conditions of no lime application were subtracted from the carbon dioxide utilized, the figure in Section D would be even larger (calculated under these conditions to be 9.4 p.p.m. carbon dioxide).

The possibility exists, however, that in the absence of high bicarbonate concentrations but in the presence of other optimum conditions favorable to the occurrence of a plankton bloom, the rate of carbon dioxide supply from the lake sources (respiration, decomposition, and atmospheric absorption) may be increased to a rate that would supply the demands of photosynthesis. This possibility would depend upon a physical-chemical demand produced by the removal of carbon dioxide by the algae from existing chemical systems in equilibrium; but the presence of carbonates also produces a demand upon carbon dioxide and changes the normal carbon dioxide relationships. The question, then, remains: Can intense photosynthetic demand for carbon dioxide increase the carbon dioxide production from the lake's respiratory activities (respiration, decomposition, and atmospheric absorption) above that rate supplied to react with carbonate? The ability of some algae, at least, to exract carbon dioxide from carbonates as well as bicarbonates (Ruttner, 1953, p 63) would seem to indicate so. Further research into this question is indicated.

It was tentatively concluded that a causal relationship existed between the level of bicarbonate alkalinity and the phytoplankton production during the eight-day period of plankton bloom; in other words, bicarbonate alkalinity provided a reservoir of immediately available carbon dioxide which was utilized under conditions of intense photosynthetic activity (plankton bloom) after free carbon dioxide had been exhausted and the further production of carbon dioxide by the lake was insufficient to provide for the phytoplankton's photosynthesis under the high rate of utilization existing at the time of bloom.

The higher levels of phosphorus concentration in the central epilimnion of Starvation Lake (see Figure 5) found soon after lime application may

have been responsible for stimulating the *Microcystis* bloom. The reservoir of carbon dioxide in the bicarbonates might then have been responsible for permitting the bloom by furnishing carbon dioxide in excess of that produced by the lake. After the beginning of the bloom total phosphorus concentrations decreased, probably because of the fall of the plankton bodies out of the epilimnion after utilizing the phosphorus.

The effects of alkalinity upon phytoplankton production may be summarized in the following hypotheses which received support from the present study. (1) In soft-water lakes the bicarbonate alkalinity (or "reservoir" of immediately available carbon dioxide) may limit the rate of carbon dioxide utilization and thus the rate of phytoplankton production, but apparently does not limit the level to which the standing crop of phytoplankton may reach providing the rate of carbon dioxide production by the lake is equal to or greater than the rate of carbon dioxide utilization. (2) Under optimum conditions of alkalinity the availability of nutrients such as phosphorus is improved, and the availability of such nutrients probably limits the level of standing crop.

It appears possible now to summarize the reasons for observed differences in production in lakes with different conditions of alkalinity. (1) Hard-water, or alkalitrophic, lakes appear to suffer poor productivity because of the adverse effects of excess calcium upon the availability of nutrients (Barrett, 1953). (2) Medium-hard lakes with optimum conditions of alkalinity provide large reservoirs of immediately available carbon dioxide in the form of bicarbonates and permit phytoplankton "blooms." These lakes may also provide optimum nutrient availability. (3) Soft-water lakes, such as acid bog lakes, may not permit as intense plankton blooms because of the lack of high concentrations of immediately available carbon dioxide in the bicarbonate form and also limit total production because of poor availability of nutrients.

Acknowledgments

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FISH TAGS AND TAGGING IN QUEBEC WATERS[1]

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ABSTRACT

During the 12-year period, from 1945 to 1956, 19,310 fish of 13 species were tagged in Quebec. Three types of tags were used. From 1938 to 1940, monel metal strap tags, adapted from the "cattle ear tag" were tried, but were discarded as unsatisfactory. Since 1940 two different types designed by the author have been used. Ring-shaped strap tags of monel or nickel have been found satisfactory for tagging some species such as sturgeon, channel catfish, and eel. For other fishes, such as shad, smelt, striped bass, tomcod, split ring and plate tags are more advantageous. In the case of two species of sturgeon, several fish with strap tags were recovered 10 and 11 years after liberation. The maximum distances between tagging and recovery points in Quebec tagged fishes were 892 miles for Atlantic sturgeon and 1,650 miles for shad.

INTRODUCTION

Since 1938, under the supervision of the author more than 25,000 fish of 13 species have been tagged and released in Quebec waters. The present paper deals with tag returns obtained during the 12-year period from 1945 to 1956 but not with recaptures made after August 1, 1956. Of 13 species tagged, principally in the St. Lawrence River, only eight commercial fishes will be discussed here.

TYPES OF TAGS USED

Three types of fish tags have been used, the two latest models of which were designed by the author.

CATTLE EAR TAG

From 1938 to 1940 two sizes of monel strap tags, adapted from the cattle ear tag were employed exclusively. Both sizes were very similar to those described and illustrated by Rounsefell and Kask (1945, Figs. 43 and 45.) These tags were unsatisfactory, because they did not allow growth of the bones to which they were attached. When they were placed on the lower jaw of a speckled trout, the pressure of the metal caused reabsorption of the boney tissue, and this permitted the tags to fall off in a few months.

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[1] No. 55, Department of Fisheries, Quebec.

Ring-shaped Strap Tag

In 1940 monel and nickel strap tags, bent into the shape of a ring and resembling the "Heincke ring" (see Rounsefell and Kask, 1945), were first used. Two sizes of these tags, one 5/8" and the other 1 inch in diameter were employed. In the following discussion these tags are referred to as "strap tags."

Strap tags were placed on the lower jaw of fish of several species such as channel catfish, eel, shad, smelt, striped bass, tomcod, and trout. With the two species of sturgeon the tags were fastened through the skin and cartilage at the front edge of the dorsal fin. Strap tags are inserted through a hole made with a sharp ice pick or the sharpened end of the tag. The two ends of the tag are then clinched with an ordinary but preferably long-nosed pliers as described by Vladykov (1950). This type of tag is easily and quickly attached, and is retained by the fish for several years. Its main disadvantage is the thinness (1/64 inch) of the metal may cause the edge to cut the neighboring tissues.

Split Ring and Plate Tag

We designed in 1950 a new type of tag, which may be called "split ring and plate tag." This model consists of a metal split ring and a plate of laminated vinylite. A brief description of this tag was given in the Journal du Conseil Guide to Fish Marks (1953, p. 250). Three sizes of split rings, made of stainless steel piano wire, were manufactured: 3/8, 5/8, and 7/8 inch in diameter. They can be opened sideways by means of specially designed pliers, one for each ring size. The tags or plates, attached to the split rings, carry on one surface the inscription "Departement des Pecheries, Quebec," and a number and a letter on the other. This plate is made of laminated vinylite of different colors and in two sizes, 3/5 x 1/4 of an inch, and 1 x 1/3 inch. The split rings and tags are placed on the lower jaw of the fish.

The advantage of the split ring and plate tag over the others is that the split ring is made of round wire and hence has a non-cutting edge. The original laminated vinylite tags were only 0.02 inch in thickness and therefore quite breakable. We are planning to use new laminated plates which will be three times thicker. To prevent the split rings from opening, as for instance, when the tagged fish becomes entangled in nets, we are experimenting with a portable spot-welder to weld the ends of the ring after being placed on the fish. So far the results are encouraging.

It is our opinion that split ring tags are very suitable for the tagging of shad and damage the fish much less than the "cheek tag" designed by Miss Cable (1950). Results from application of split rings to smelt are very encouraging, and, this type of tag may well be more durable than the celluloid opercular tags used by McKenzie (1950) for the same fish in the Miramichi estuary.

Comparative Returns from Two Types of Tags

It is very difficult to estimate accurately the merits of the different types of tags, which were used on several species of fishes of different sizes, life spans and behaviours, but some general comments can be made.

For large and tough skinned fishes, such as sturgeon, ring-shaped strap tags are very satisfactory, and there is no need for lighter types. Of 1,005 lake sturgeon tagged during the period 6.7 percent have been returned and of 1,948 tags applied to Atlantic Sturgeon 25.9 percent have been returned. On the other hand, smaller fishes such as smelt, tomcod and trout carry the split ring tags much better. For young specimens of any fish, light and easily seen split ring tags are especially suitable. In the case of eels, strap tags attached to the lower jaw give the better results, up to 11 percent return, than the split rings which had a return of 6 percent. However, some eels were recaptured after three years and still carried undamaged split ring and plate tags. Returns from strap tags were much higher (11 percent) than for split rings (3 percent) in the case of channel catfish. As shown in Table 1 the tag returns from shad and striped bass were higher for split ring tags than for strap tags.

It should be kept in mind, that the returns of tags vary greatly and are not strictly comparable between species, not only because of the different types of tags used, but mainly due to the differences in the intensity and type of fishing as well as the size of fish tagged and the season of tagging. For instance, tomcod that were caught on hook and line in the winter through the ice, during the spawning season, apparently survived tagging manipulations very poorly, for the tag returns were less than one percent. Perhaps handling of the fish when full of spawn or at too great a difference between the water temperature (32°F.) and the warmth (about 70°F.) of the fishing cabin were responsible for this. On the other hand, tomcod, caught with line during summer or autumn, survived tagging very well, and their returns varied from 10 to 20 percent.

Maximum Time Between Tagging and Recovery

Recently certain authors (Callhoun, Fry, and Hughes, 1951) claimed that because of corrosion, tags made of monel and nickel are not satisfactory. However, in our experience strap tags made of either monel or nickel resist corrosion by salt water very well. Shad, eel, striped bass, and channel catfish carried these tags from four to eight years without any traces of corrosion. Some of our sturgeons have been recaptured after 10 to 11 years. Tags on these fish showed some corrosion, but they were mainly worn by the rubbing of the tags against the sea-bottom. Stainless steel split rings, even after four years in salt water, showed no traces of corrosion.

TABLE 1.—*Returns from tags applied to Quebec commercial fishes, with data on maximum time retained, and maximum distances re principally in the St. Laurence River, during the period 1945-1956corded between tagging and recovery stations.*
[Asterisks are used as follows: (*) strap tag; (**) split ring and plate tag and (***) cattle ear tag reshaped into ring.]

Species	Number of fish tagged[1]		Number returned		Percentage return		Maximum time between tagging and recovery	Maximum mileage between tagging and recovery stations
	Strap	Split ring	Strap	Split ring	Strap	Split ring		
Lake Sturgeon (*A. fulvescens*)	1,005 (1945-54)	—	68	—	6.7	—	*10 years	*130
Atlantic sturgeon (*A. oxyrhynchus*)	1,948 (1945-49)	—	505	—	25.9	—	*11 yrs. 34 days	*892
Atlantic shad (*A. sapidissima*)	1,783 (1945-50)	152	63	14	3.5	9.2	*4 yrs. 12 days	*1,650
Eel (*A. rostrata*)	1,664 (1945-55)	170	186	10	11.2	5.9	*5 yrs. 11 mon.	*200
Channel catfish (*I. lacustris*)	1,224 (1947-55)	538	136	14	10.9	2.6	*8 yrs. 4 days	*95
Tomcod (*M. tomcod*)	— (1953-56)	7,139	—	297	—	4.2	**2 yrs. 81 days	**135
Smelt (*O. mordax*)	— (1956)	208	—	7	—	3.4	**81 days	**90
Striped bass (*R. saxatilis*)	1,411 (1945-56)	500	107	47	7.6	9.4	***6 yrs. 10½ mon.	*180

[1]Numbers in parentheses refer to years of tagging.

Information on the longest periods between tagging and recaptures, for the eight species of fishes, is presented in Table 1.

Longest Distances Travelled by Tagged Quebec Fishes

Tagging is the only reliable source of information on the migratory habits of our fishes. It will be seen from Table 1 that smelt and tomcod can travel up to 90 to 135 miles respectively and that movements of channel catfish in the St. Lawrence River region are rather limited and did not exceed 95 miles. Maximum travel of striped bass in the St. Lawrence River did not exceed 180 miles.

The migratory habits of two species of sturgeon are very different. Movements of lake sturgeon apparently did not exceed 130 miles. The Atlantic sturgeon can travel much greater distances. A fish tagged on July 31, 1947 at Isle-aux-Coudres, was recaptured on June 3, 1948 at Fox Point, at the entrance to St. Margaret's Bay, Nova Scotia, thus having travelled at least 892 miles. During the period of somewhat less than a year between tagging and recovery it grew from 28 to 36 inches in fork length and increased in weight from four to 11 pounds.

Some tagged Quebec shad were recaptured along the Atlantic sea-coast. The most distant recovery was that of a female shad tagged on June 5, 1948 at Isle Verte and recaptured on April 13, 1949 at Old Point Comfort, Virginia, at the entrance to Chesapeake Bay. Further details on distant recaptures of shad are given in another paper (Vladykov, 1956).

The greatest distance at which tagged Quebec eels (adult females) were recaptured was 200 miles. This is far from their spawning grounds in the Sargasso Sea but commercial fishery for eels in Quebec is not practiscd farther east than Rivire-du-Loup.

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INTERRACIAL HYBRIDIZATION OF CUTTHROAT TROUT, *SALMO CLARKII,* AND ITS USE IN FISHERIES MANAGEMENT

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ABSTRACT

Two races of coastal cutthroat trout *(Salmo clarkii)* were hybridized and the resultant first generation hybrids were compared with the two parent races. In both laboratory and field studies the hybrids showed evidence of hybrid vigor. The catch of sports fishermen, during two seasons at Echo Lake, Washington, where both parent and hybrid trout were planted, was composed of three to six times as many fish of the hybrid stocks as of the parent races.

INTRODUCTION

From earliest times man has made continual efforts to improve the quality of the plants and animals that provide for his needs. Few experiments, however, have been carried out to improve the quality of fish, although fish have been found to be very susceptible to modification by selective breeding. Among fishes, only the goldfish *(Carassius auratus)* has a long history of purposeful breeding. Smith (1924) credits the late Professor John A. Ryder with the statement that varieties of goldfish "are the most profoundly modified of any known race of domesticated animal organisms." Not only have profound changes in form and color of goldfish been brought about, but also modification of the bony structures such as the bilateral splitting of the caudal fin has been achieved.

Studies with salmonoid fish at the School of Fisheries, University of Washington, over the past 25 years (Donaldson and Olson, 1955) indicate that rainbow trout *(Salmo gairdnerii)* can be improved by selective breeding to have earlier maturity, more rapid growth, increased fecundity, resistance to disease, and changed season of spawning. Selective breeding experiments with cutthroat trout *(Salmo clarkii)* have been carried out at the School of Fisheries with similar results.

In addition to the selective breeding of stocks of plants and animals to develop improved strains, interracial hybridization of races of the

same species may be desirable to produce hybrid stocks with increased vigor. Almost all of the corn produced in this country is grown with hybrid seed. Gowen (1952) sums up the contribution of hybridization to corn culture: "Iowa's indebtedness to heterosis, generated through crossing selected and repeatedly tested inbred strains, is well known. Few outside workers in the field realize the full magnitude of this debt."

After years of selective breeding of populations of fish, with the development of highly inbred strains, the next step would be to out-cross with the best stocks available to obtain hybrid stocks for laboratory and field testing. In the spring of 1953 such experiments were initiated with cutthroat trout at the University of Washington, with the laboratory studies of 1953 and 1954 preceding the field trials of 1955 and 1956.

Laboratory Experiments with Hybridization of Cutthroat Trout

The coastal cutthroat trout *(Salmo clarkii)* is found in almost all of the coastal lakes and streams from northern California to southeastern Alaska. Clemens and Wilby (1949) describing the fish in British Columbia state:

> The coastal cut-throat trout spawns usually from February to May in small streams, although in the Cowichan river system it has been found to spawn as early as December. The young may descend to the sea in their second or third year, taking up an estuarine or marine life for one or more years. These estuarine fish frequently enter the lower reaches of streams in the spring and feed upon young salmon migrating seaward. Apparently they return to the sea and re-enter the streams in the autumn and winter on a spawning migration. Some individuals remain in fresh water throughout their lives.

The stock of cutthroat trout maintained at the School of Fisheries, University of Washington, was obtained from Mathews Creek, a tributary of Lake Washington. Adult fish were seined from the spawning run in the spring of 1933. The progeny of this initial transfer were reared at the University where they were subjected to rigorous selection for season of spawning, rapid growth, early sexual maturity, increased fecundity, disease resistance, and efficient utilization of food. After 20 years of selection, the characteristics of the stock maintained at the University had become well fixed.

For out-crossing with the University stock, a stock of coastal cutthroat trout was obtained from Lake Whatcom, a large lake 75 miles north of Seattle. These fish, of the same species *(Salmo clarkii)* as the University stock, were obtained from wild fish which had entered the spawning trap of the Washington State Department of Game in the spring of 1950. Offspring of the Lake Whatcom race used in the first crossbreeding experiments were transferred to the University on January 20, 1952. They were 2-plus years of age.

Fish of the two races were first crossed in the spring of 1953 and again in 1954 and 1955. Because the rate of growth of the Lake Whatcom race was slower than the University race and the age at maturity later,

fish of the Lake Whatcom race were one or more years older than fish of the University of Washington race when crossed. For the 1953 cross, fish of the University stock approaching two years of age and the Lake Whatcom fish three years of age were used. The differences in the two races were evident also in aspects other than age at maturity. Some of the differences are shown in the comparisons of Table 1 and Figure 1.

The Lake Whatcom fish from wild stock, although a year older than the fish of the University stock, were much smaller, produced fewer eggs and a smaller percentage of the females were sexually mature.

Each spring as the fish of the two stocks reached maturity they were spawned and reciprocal crosses were made. To accomplish the crosses, the eggs produced by half of the females of each race were fertilized by male fish of their own race and the eggs of the other half by males of the other race. This procedure produced four groups of fish each year:

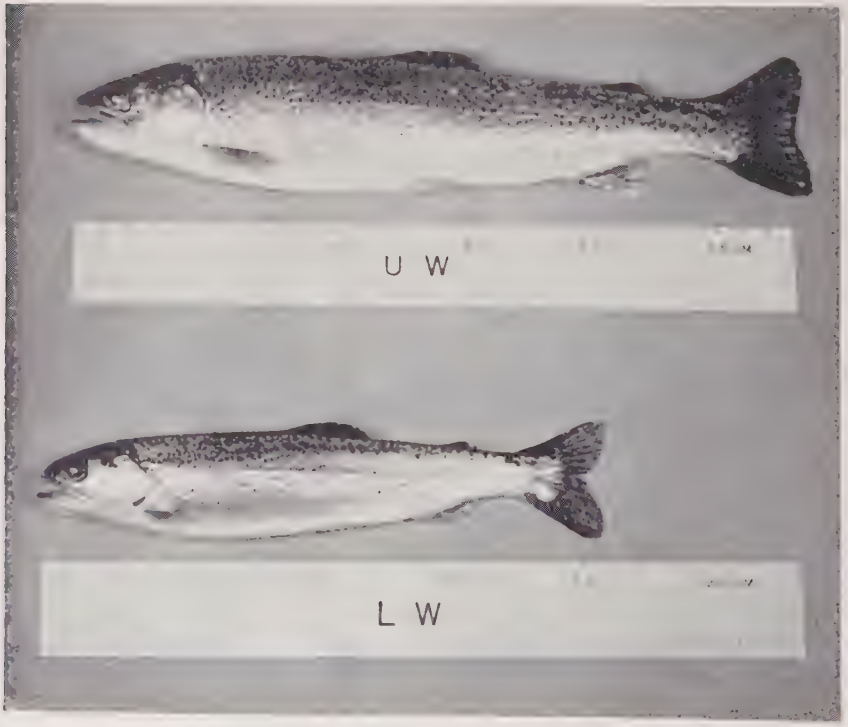

FIGURE 1.—Cutthroat trout *(Salmo clarkii)*, approximately 1 year old, reared in the same pond at the University of Washington Experimental Hatchery. Upper, University of Washington stock (UW); lower, Lake Whatcom stock (LW).

two reciprocal F_1 generation hybrids and two straight-line parent races. The fish of the four lots were marked by fin amputation. Those of the Lake Whatcom race had the left ventral (LV) fin removed; the University of Washington race, the right ventral (RV) fin; those of the Lake Whatcom female-University of Washington male cross, the adipose and left ventral (A-LV) fins; and the University of Washington female-Lake Whatcom male hybrids, the adipose and right ventral (A-RV) fins.

During the spring of 1954, the Lake Whatcom stock were again crossed with the University of Washington population to produce four groups of fish that were to be used for field-growth and survival experiments. After hatching, the four groups of fish (two parent groups and two reciprocal hybrids) were reared in the hatchery in separate lots until they were large enough to be marked by fin clipping. They were sampled to determine comparative growth before release into Echo Lake (Table 2).

TABLE 1. — *Comparison of racial stocks of cutthroat trout used in the 1953 hybridization experiment*

	University race	Lake Whatcom race
Age of fish in years	2	3
Average length of females[1]	37.7	28.1
Average length of males[1]	37.0	29.5
Average number of eggs at initial spawning	1,238	362
Percentage of mature females	66	11

[1] Length from the tip of the snout to the shortest rays of the caudal fin in centimeters.

Echo Lake (Figure 2), which was used for the field study, is a small brown-water lake northeast of Seattle, Washington. It is typical of many lakes west of the Cascade Range. The area around the lake is covered with second growth timber that has grown up since the region was logged about 35 years ago. The lake was studied during a year's cycle by Buckridge (1956).

The lake, as surveyed in 1952, has 17 acres of surface area, a maximum depth of 50 feet, and a computed volume of 94,454,000 gallons. During the summer months the surface temperature of the water reaches 68°F. Stratification of the water develops during the summer months with the thermocline between the 5- and the 25-foot levels. The stratification lasts until December at which time the lake has a uniform temperature of 44°F. The minimum temperature of 40°F. is reached in January and by February the surface waters begin to warm again. During the summer stratification almost no oxygen is found below 20 feet.

FIGURE 2.—Echo Lake on opening day of the fishing season, April 17, 1955.

TABLE 2.—*Length-weight measurements and number of cutthroat trout fingerlings in each of four lots released into Echo Lake in 1954*

Stock	Mark	Progeny		Number planted
		Average length in centimeters[1] Aug. 5, 1954	Average weight in grams Aug. 5, 1954	
University female..... University male.....	Right ventral.....	7.51	5.18	3,006
University female..... Lake Whatcom male...	Adipose—right ventral...	7.97	5.46	2,213
Lake Whatcom female . University male.....	Adipose—left ventral....	7.55	5.18	4,802
Lake Whatcom female . Lake Whatcom male...	Left ventral.....	6.84	3.48	5,890

[1] Length from the tip of the snout to the shortest rays of the caudal fin in centimeters.

The original population of fish in Echo Lake was modified during the past years by the introduction of non-native fish. These fish upset the natural balance of the native fish populations. To correct this condition the lake was treated on September 23, 1953, with 900 pounds of rotenone to remove the undesirable fish.

Following application of the rotenone Echo Lake was barren of fish until February 1954, when 6,000 rainbow trout fingerlings were planted. An additional 6,000 were released in the lake during April 1954. Almost all of the rainbow trout were caught during the open season of 1954. Some, however, escaped the very intensive sports fishery. On April 17, 1955, the opening day of the sports fishing season, 60 rainbow trout were caught. These fish had an average length of 34.7 centimeters (13.7 inches) and an average weight of 465 grams (1.02 pounds). Two additional rainbow trout were caught on opening day, April 22, 1956. One measured 46 centimeters (18 inches) and weighed 1,347 grams (2.97 pounds), the other was 52.5 centimeters (20.7 inches) in length and weighed 2,268 grams (5.0 pounds).

Growth of 1954 Brood Year Cutthroat Trout

During the summer of 1954 a total of 15,911 cutthroat trout fingerlings of the four lots were planted in Echo Lake (Table 2). A random sample of 500 fish from each of the four lots of fish was retained at the University Experimental Hatchery for a comparison of growth with those released into the lake. Several times during the study, measurements of length and weight of the fish were made. Representatives of the four groups were weighed and measured on August 5, 1954, before being divided into those lots to be retained at the hatchery or planted into Echo Lake (Table 3). At that time, the fingerlings from the hybrid lots were slightly larger than either of the parent lots.

The fish held at the hatchery were examined again on November 20, 1954 (Table 3). At the second weighing and measuring the University race of fish were largest, the Lake Whatcom smallest and the hybrids intermediate.

A third evaluation of the growth of the fish held at the hatchery was made on April 16, 1955 (Table 3). The following day, April 17, the fish in Echo Lake were sampled from the opening day fisherman's catch (Table 3).

Buckridge (1956) in evaluating the growth of the four groups of fish comments:

> In analyzing the lengths of the four groups of fish in the lake and the four in the hatchery it was found that neither the lake fish nor the hatchery fish had a common variance (Dixon and Massey, 1951). This precluded the use of variance analysis and therefore a modification of the standard t-test (Welch, 1938) was chosen as appropriate for evaluating the difference in length.

The mean lengths of all groups tested, except the University group and the two hybrid groups in the lake were found to be different at the five percent level of significance. A similar analysis of the weights showed only two groups, the hybrids held in the hatchery, not to differ from one another. In both environments the University fish were largest, the Lake Whatcom fish smallest and the hybrids intermediate.

Production of Cutthroat Trout in Echo Lake

Samples of the fish populations in Echo Lake were obtained by netting and from the sports fishermen. The opening day's catch (April 17, 1955) was evaluated as thoroughly as possible. All fishermen fishing the lake were interviewed and their catch, totalling 488 cutthroat trout, was examined for fin clip marks and the length and weight of each fish determined.

Table 3.—*Lengths in centimeters and weights in grams of samples of hatchery-reared and lake-reared cutthroat trout*

Stock	U♀ X U♂	U♀ X LW♂	LW♀ X U♂	LW♀ X LW♂
Mark	Right ventral	Adipose—right ventral	Adipose—left ventral	Left ventral
August 5, 1954—hatchery fish				
Average length	7.51	7.97	7.55	6.84
Average weight	5.18	5.46	5.18	3.48
Number	100	100	100	100
November 20, 1954—hatchery fish				
Average length	16.63	16.46	15.81	13.69
Average weight	64.53	53.85	48.41	30.30
Number	128	142	133	90
April 16, 1955—lake fish				
Average length	24.72	23.80	23.38	20.49
Average weight	189.20	151.10	151.37	96.98
Number	157	137	121	66
April 17, 1955—lake fish				
Average length	20.55	19.61	20.43	18.80
Average weight	98.43	79.21	88.47	66.22
Number	28	118	281	32

The yield of the four groups of marked fish differed markedly (Table 4). The hybrid groups combined made up only 44 percent of the number of fish planted but produced 87 percent of the fish caught by the fishermen.

The weight of fish caught was also greatly in favor of the hybrid fish (Table 5). The two groups of hybrids combined comprised 49 percent of the total weight of fish planted, with the combined parent stocks making up 51 percent of the planting weight. In the opening day sportsmen's catch, however, the hybrids made up 87 percent of the weight of fish caught, while the combined non-hybrid groups provided only 13 percent.

TABLE 4.—*Cutthroat trout caught in Echo Lake on April 17, 1955*

Mark and stock	Number planted	Number caught	Percent caught of number planted
Right ventral (U♀ X U♂)	3,006	30	0.99
Adipose—right ventral (U♀ X LW♂)	2,213	124	5.60
Adipose—left ventral (LW♀ X U♂)	4,802	299	6.20
Left ventral (LW♀ X LW♂)	5,890	35	1.70

TABLE 5.—*Comparison of total weights of fish of each of the four groups planted in 1954 and caught on opening day of the 1955 fishing season*

Mark and stock	Weight of fish planted (pounds)	Weight of fish caught (pounds)	Percent catch of weight planted	Percent catch of weight taken
Right ventral (U♀ X U♂)	34.29	6.50	18.96	7.10
Adipose—right ventral (U♀ X LW♂)	26.61	21.63	81.60	23.64
Adipose—left ventral (LW♀ X U♂)	54.78	58.26	106.34	63.68
Left ventral (LW♀ X LW♂)	45.15	5.10	11.30	5.57
Total	160.83	91.49	56.89	

TABLE 6.—*Growth and percentage return of 1-year-old cutthroat trout taken from Echo Lake by sports fishermen on opening day of the 1956 fishing season*[1]

Mark and stock	Number planted	Average weight (grams)	Number caught	Average weight (grams)	Average length (centimeters)	Percent caught of number planted
Right ventral (U♀ X U♂)	1,792	1.82	17	106.7	21.0	0.95
Adipose—right ventral (U♀ X LW♂)	3,390	1.60	116	96.2	20.5	3.42
Adipose—left ventral (LW♀ X U♂)	2,897	1.95	82	94.0	20.2	2.83
Left ventral (LW♀ X LW♂)	2,662	1.34	16	80.3	19.4	0.60
Total	10,741		231			2.15

[1] Fish planted on June 22 and July 11, 1955; fish caught on April 16, 1956.

The total catch of cutthroat trout in Echo Lake on opening day was 5.8 pounds of fish per surface acre of lake.

Fishing continued at Echo Lake throughout the 1955 season, and the creel census indicated that cutthroat trout were caught in about the same proportions from the four groups as on the opening day of fishing, with the hybrid stocks providing the greater number and weight of fish.

1955 Stocking and Resultant Catch in Echo Lake

The two races of cutthroat trout in the brood ponds at the University Experimental Hatchery were hybridized for the third time in the spring of 1955, and the 10,741 fingerlings of the four groups were planted in Echo Lake (Table 6). The 1955 stocking took place on June 22 and July 11, thus was earlier in the season and contained fewer fish of smaller size than the 1954 planting.

On the opening day of the sports fishing season, April 16, 1956, the total sports catch from the lake was again examined for marked fish and the fish making up the catch were weighed and measured.

A total of 231 1-year-old cutthroat trout with identifiable marks were measured. As in the 1955 sportsman's catch the 1956 sample was composed dominantly of the hybrids (Table 6). The combined hybrid lots made up 59 percent of the number of fish stocked but accounted for 88 percent of the number of fish caught. Fish of the University race were again the largest, the Lake Whatcom race made the poorest growth, and the two hybrid stocks were intermediate in size.

A very striking difference was evident in the weights of fish of the various lots in the opening day's catch (Table 7). A total of 39.43 pounds of fingerlings were planted into Echo Lake in the summer of 1955. On the opening day of the 1956 fishing season the sport fishermen caught 48.39 pounds of fish identified with the marks of the four lots. The

Table 7.—*Comparison of weight of fingerling cutthroat trout planted with weight of anglers' catch of 1-year-old fish from Echo Lake on opening day of the 1956 season*[1]

Mark and stock	Weight of fish planted (pounds)	Weight of fish caught (pounds)	Percent catch of weight planted	Percent catch of total weight taken
Right ventral (U♀ X U♂)	7.18	4.00	55.8	8.27
Adipose—right ventral (U♀ X LW♂)	11.95	24.58	206.7	50.79
Adipose—left ventral (LW♀ X U♂)	12.44	16.98	136.5	35.09
Left ventral (LW♀ X LW♂)	7.86	2.83	36.0	5.85
Total	39.43	48.39	122.6	100.00

[1] Fish planted on June 22 and July 11, 1955; fish caught on April 16, 1956.

parent stocks, however, accounted for only 14.12 percent of the weight of the catch while the two hybrid lots produced 85.88 percent of the poundage.

Carry-over of 1954 Brood Year Cutthroat Trout into 1956

On the opening day of fishing in Echo Lake, April 16, 1956, in addition to the 231 cutthroat trout of the 1955 year-class, 97 marked cutthroat trout of the 1954 year-class were caught (Table 8). These 2-plus-year-old fish were so much larger than the 1-plus-year-old stocks that although the same marks were used each year there was so little overlap that fish of the 2-year class could be separated by size alone. Fish 25 centimeters (9.84 inches) or more in total length from the tip of the

Table 8.—*Growth and return to the angler of 2-year-old cutthroat trout from Echo Lake on opening day of the 1956 season*[1]

Mark and stock	Number planted	Average weight in grams when planted	Number caught	Average weight (grams)	Average length (centimeters)	Percent caught of number planted
Right ventral (U♀ X U♂)	3,006	5.18	9	289.3	28.8	0.30
Adipose—right ventral (U♀ X LW♂)	2,213	5.46	19	256.0	29.0	0.85
Adipose—left ventral (LW♀ X U♂)	4,802	5.18	21	338.3	31.1	0.44
Left ventral (LW♀ X LW♂)	5,890	3.48	48	321.3	31.2	0.81
Total	15,911		97			

[1] Fish planted in August 1954; fish caught on April 16, 1956.

Table 9.—*Comparison of weight of fingerling cutthroat trout planted with weight of anglers' catch of 2-year-old fish from Echo Lake on opening day of the 1956 season*[1]

Mark and stock	Weight of fish planted (pounds)	Weight of fish caught (pounds)	Percent catch of weight planted	Percent catch of total weight taken
Right ventral (U♀ X U♂)	34.29	5.74	16.74	8.69
Adipose—right ventral (U♀ X LW♂)	26.61	10.71	40.25	16.21
Adipose—left ventral (LW♀ X U♂)	54.78	15.65	28.57	23.55
Left ventral (LW♀ X LW♂)	45.15	33.97	75.24	51.42
Total	160.83	66.07	41.08	

[1] Fish planted in August 1954; fish caught on April 16, 1956.

snout to the shortest rays of the caudal fin were judged to be 2-plus years old and of the 1954 stocks. The second year after planting, the take of the Lake Whatcom race (LV) was greater than that of the University race (RV) and of the hybrids. This increased catch of fish of the Lake Whatcom race may have been due to the very slow rate of growth of these fish during their first year in the lake, which made them less vulnerable to fishing pressure than the more rapidly growing hybrid fish. The Lake Whatcom (LV) 2-year-old trout contributed 33.97 pounds of fish (Table 9) to the 1956 catch, which was 51.42 percent of the total weight of 2-year-old fish caught.

On opening day of the 1956 season, anglers took from Echo Lake 6.73 pounds of cutthroat trout per surface acre. It is regretted that figures for the total production of fish of the four groups for the entire year are not available. However, it is apparent from the laboratory and field tests with selected races of cutthroat trout and the hybrids produced by crossing the two races that there are many advantages of hybridization in fisheries management.

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SOME FACTORS RELATED TO SUCCESS OF FISH POPULATIONS IN IOWA FARM PONDS[1]

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ABSTRACT

Minnow seines and larger bag seines were used to determine the reproductive success of fish in all (60) farm ponds known to have been stocked with fish in Marion County, Iowa. Additional data on lengths, weights, ages, and abundance of the fish were collected from many of the ponds. Ponds smaller than 0.5 acre were less successful than larger ponds. Fifteen of 26 ponds stocked with the bass-bluegill-bullhead combination were successful, and four of 18 ponds stocked with the bass-bluegill-bullhead combination were successful. The rates of stocking within the range of 300 to 1,000 bluegills per acre in combination with bass had little influence on success or failure of fish ponds. Pond management practices by the farm operator were generally limited to fencing for exclusion of livestock. The ponds were not heavily fished, and harvest did not exceed 65 pounds of fish per acre per year at the most heavily fished ponds. Clay turbidity probably delayed growth of bass. Aquatic vegetation was not important in determining success of fish populations. Winterkill occurred one or more times in the fish populations of 31 of the 60 ponds.

INTRODUCTION

Causes of fish pond success have been the subject of considerable controversy but it is generally agreed that the term "success" can be defined as ability to produce fish desired by man. Swingle (1945) regards a proper balance between largemouth black bass and bluegills as the most important factor in the production of good fishing in impounded water. He further states that enough bass must be available to keep the bluegill reproduction in check, and yet bass must not be so abundant that too few bluegills survive to produce food for the bass. Bennett (1944) states that Illinois lakes that produced substantial yields of fish have the following characteristics: (1) predatory fish are numerous; (2) no one species dominates, especially rough or forage fish, and (3) fishing is intensive but not selective.

Following the usual definition, a successful fish pond is here regarded as one providing, or capable of providing, a crop of harvestable fish

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over a period of years. A minnow seine was used to determine the presence of young-of-the-year fish and the condition or "balance" of the population interpreted according to the criteria established by Swingle (1945) and Anderson (1948). Larger seines were used to give further data on the fish populations. Fish seined were measured and weighed, and scales taken so that the age and growth of the fish could be determined. In 14 ponds, size of fish populations was estimated by the marking and recovery technique (Carlander and Moorman, 1956).

The present study of 60 Iowa fish ponds attempts to determine the influence of several factors on the success of each pond. It is not to be expected that all factors determining the success or failure of a pond can be ascertained or measured or that such factors operate independently. Since this study was observational rather than experimental in nature, it was often not possible to detect relationships between factors responsible for success or failure of a pond.

The 60 ponds, all in Marion County, were examined during the summers of 1949, 1950, and 1951. To prevent selection bias, all ponds known to have been stocked with bass and bluegill, with or without other species, were investigated. Soils maps (Simonson and Benton, 1941) revealed that most of the ponds were on silt loam soils in the Tama and Muscatine series of loess origin and the Shelby series of glacial till origin. Where these soils were badly eroded, subsoils of silty clay loam and clay were exposed.

Pond Size and Success

Size of ponds studied ranged from 0.1 acre to 2 acres. The success of ponds smaller than 0.5 acre was usually less than that of ponds between 0.5 and 1 acre (Table 1.) However, both successful and non-successful ponds were well distributed over the size range except that ponds of 0.1 acre were not successful.

Anderson (1948) found that in small ponds (0.1 acre) it was extremely difficult to maintain enough bass to control the bluegill population, and recommended 0.25 acre as a reasonable minimum size for fish ponds. Swingle (1949) reports that unfertilized ponds of less than 0.5 acre and fertilized ponds of less than 0.25 acre are too small to insure good results with the bass-bluegill combination. Krumholz (1950a) reported good success in 0.1 acre ponds with redear sunfish and either largemouth or spotted bass. He limited his recommendations for the bass-bluegill combination to ponds of 1 acre or larger (Krumholz, 1950b). Ponds of at least 0.5 acre in size are recommended for Iowa (Hull, Wilcox and Speaker, 1950).

Species of Fish Stocked

The largemouth black bass and bluegill combination originally found most suitable for Alabama ponds (Swingle and Smith, 1940) has usually

TABLE 1.—*Size and success of Iowa farm fish ponds*

Pond area in acres	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	Over 1.0
Number of ponds	2	7	19	10	8	6	3	1	2	2
Percentage successful	0	43	37	40	50	67	67	100	50	50

been the basis for stocking Iowa ponds. Other species have been added on the basis of experience in fish management of small lakes. Still others have either been accidentally included in official stockings or have been stocked by individuals, mostly because of their availability in nearby streams. In Marion County, most stocking of farm ponds has been done through the cooperative program of the Soil Conservation District and, to a lesser degree, by the State Conservation Commission. Accordingly random and unplanned stocking of fish by individual farmers has been at a minimum, and only a few fish species have been stocked. Fish species officially and unofficially stocked in the study ponds are:

Officially stocked

Largemouth black bass ..... *Micropterus salmoides*
Bluegill ..... *Lepomis macrochirus*
White crappie ..... *Pomoxis annularis*
Black bullhead ..... *Ameiurus melas*
Golden shiner ..... *Notemigonus crysoleucas*

Unofficially stocked

Green sunfish ..... *Lepomis cyanellus*
Orangespotted sunfish ..... *Lepomis humilis*
Fathead minnow ..... *Pimephales promelas*
Goldfish ..... *Carassius auratus*

Of the 26 ponds where bass and bluegills composed the original stocking, 15 were judged successful during the period of study 1949-1951 (Table 2). Bass-bluegill ponds normally contained reproducing populations and harvestable fish 2 years after stocking but in some cases not until the 3rd year. Two of the 4 best fishing ponds were bass-bluegill ponds, and a third was essentially so during the study. Of the bass-bluegill ponds that failed, the suspected or known cause was winterkill.

Bass, bluegills and bullheads were frequently stocked as a combination prior to 1946. At that time the bullheads were withdrawn from the combination by both state and federal agencies offering fish for ponds. Of 18 ponds originally stocked with this combination, 4 were successful during the study. In 2 of the 4, bullheads were no longer in evidence either as young or as adults; one contained sub-adult and adult bullheads,

but no young bullhead reproduction was seen during the 3 years. The 4th pond still showed successful bullhead reproduction seven years after the original stocking was made. In the series of 14 bass-bluegill-bullhead ponds that failed, there is no indication that the bullheads were responsible for the poor survival or poor reproduction of either bass or bluegills, although they may have been involved in slow growth of these species. Where stocked with bullheads, bass were apparently able to reach maturity and to control the reproduction of the bullheads.

In two ponds (Pond 23 and Pond 29) miscellaneous fishes, including crappies, green sunfish, orangespotted sunfish and golden shiners, were either accidentally included in the original stocking or were subsequently

TABLE 2.—*Relationship between species stocked and success of Iowa farm fish ponds*

Species stocked	Number of ponds	Percentage successful
Bass and bluegills	26	58
Bass, bluegills and bullheads	18	22
Bullheads	7	0
Bass, bluegills and crappies	3	100
Bass, bluegills and golden shiners	1	100
Miscellaneous species	3	67
Bluegills and bullheads	2	0

stocked by persons unknown. Both ponds had overcrwded populations of these fishes, and few or no bass.

Of 7 ponds originally stocked with bullheads alone none had maintained or showed promise of maintaining annual crops of harvestable fish. Two contained populations of stunted bullheads; 2 had received plantings of bass and bluegills on top of the bullhead populations. The bass and bluegills failed to survive in these ponds.

Successful populations of fish were established in all three ponds originally stocked with a bass-bluegill-crappie-bullhead combination or with a bass-bluegill-crappie combination. Crappies were still present and reproducing in these ponds, but the bullheads had almost entirely vanished. One of these ponds (Pond 6) furnished excellent fishing.

Three ponds had received stockings of miscellaneous species of fish apparently obtained from nearby streams or ponds. In two of these, bass, bluegills and crappies were maintaining themselves and the ponds were judged to be successful (Pond 2 and Pond 42.)

One pond (Pond 12) had been stocked with a combination of bass, bluegills and golden shiners. At the end of 6 years the golden shiners

were still in evidence but in very small numbers. Bass and bluegills were well established.

The final two ponds had been originally stocked with bluegills and bullheads, without bass as a predator. One of these had subsequently received a stocking of bass, and the population was balanced. The other pond had become overcrowded with bullheads and was treated with rotenone during this study and restocked with bass and bluegills (Pond 55).

The ratio of bluegills to bass stocked in the ponds often differed from the 10 to 1 ratio advocated for the state. The ratio varied from a low of 4 to 1 (Pond 43) to a high of 25 to 1 (Pond 13). There was no discernible correlation between the stocking ratio of bluegills to bass and ultimate success of pond (Table 3).

TABLE 3.—*Stocking ratios and success of 47 Iowa farm fish ponds.*

Stocking ratios bluegills to bass	Number of ponds	Percentage successful	Stocking ratios bluegills to bass	Number of ponds	Percentage successful
4 to 1	1	100	13 to 1	5	60
6 to 1	1	100	14 to 1	2	100
7 to 1	2	0	15 to 1	1	100
8 to 1	5	0	16 to 1	1	100
9 to 1	1	100	25 to 1	1	0
10 to 1	27	44			

Although most ponds were stocked with fingerling-size fish, as recommended, Pond 45 was stocked with fry and was an effective and balanced pond 14 to 16 years later.

The rates of original stocking are known for 50 of the 60 study ponds, and are expressed in terms of the number of bluegills per acre (Table 4). For this purpose crappies are converted to the equivalent number of bluegills according to the method of Edminister (1947). Rates of stocking varied from 200 to 2,500 bluegills per acre and the majority were stocked at rates of 300 to 1,000 per acre. No apparent relationship was found between rates of stocking and future success within the stocking range for the ponds.

TABLE 4.—*Stocking rates of bluegills and success in 50 Iowa farm fish ponds.*

Stocking rates bluegills per acre	Number of ponds	Percentage successful	Stocking rates bluegills per acre	Number of ponds	Percentage successful
200	3	33	900	1	100
300	5	60	1000	7	43
400	4	25	1400	1	0
500	14	36	1500	1	0
600	2	100	1700	1	0
700	1	100	2000	3	33
800	6	66	2500	1	100

Success of Stocked Populations at Different Ages

There was no noticeable trend toward a decrease in success with increasing age of ponds that had been stocked at least two years before study (Table 5). Ponds for which only one year had elapsed since initial stocking are not included in the Table because their ultimate success or failure could not be judged. About half of the ponds that had been stocked two and three years previously were successful. Ponds stocked six years before they were first inspected represent the first ponds stocked

Table 5.—*Age of stocked fish population and success, 58 Iowa farm fish ponds.*

Years after stocking	2	3	4	5	6	15
Number of ponds	25	8	10	11	3	1
Percentage successful	48	50	30	36	100	100

through the cooperation of the local Soil Conservation District. The single pond stocked 15 years before the study was stocked by a work-group of the Civilian Conservation Corps assigned to soil conservation. The success listed for the ponds stocked more than five years before probably does not indicate an increase in success with increased age, but perhaps means that successful ponds retain their identity while unsuccessful ones disappear from both records and memory.

Management of Ponds by Farmers

If a farmer is to obtain free fish to stock his pond either from the Iowa Conservation Commission or the U. S. Fish and Wildlife Service, the pond must have required physical specifications and the area about it be subject to certain land management practices. Otherwise it is likely that fish would be wasted in unsuitable environment (Davidson, 1947: Hull, Wilcox and Speaker, 1950).

Fencing to keep livestock from wading in the pond has always been required or recommended, and is a pond management practice that can be applied directly by the farmer. Except for ten ponds where no attempt to fence was made, all pond owners had either fenced their pond or otherwise had made the pond unavailable to livestock. In some cases the cattle barrier was not maintained every year and in some the pond area was deliberately used as an additional small pasture for a few animals for a short time each year. The influence of fencing on the ability of the pond to produce harvestable fish is not discernible from the present data.

Fertilization of ponds to increase the abundance of fish foods was never mandatory, but until recent years was usually recommended. Only two farmers had complied with the recommendation in a meaningful way, and both of these farmers were deeply interested in their ponds and their

fish. In one of these fertilized ponds winterkill was a regular occurrence, and as suggested by Ball (1950) the fertilization may have contributed thereto.

It was possible to obtain only sketchy information on the amount of fishing on the study ponds. Using the information gathered, estimates of the number of fishing parties and the fish harvest were made for 18 of the ponds. These 18 ponds included those with the best populations of bass and bluegills. Twelve of the 18 had two or fewer fishing parties per month during the summer. Only six ponds might have been visited by four or more fishing parties per month. These six ponds had the two following characteristics:

1. They contained balanced populations of fish. A balanced population is here considered to be one where all species present are successful in reproducing annually.
2. The fish were of quite large size.

Accessibility of the ponds to fishermen might be considered another factor in determining fishing pressure and amount of harvest. Three of the 6 more heavily fished ponds were not easily accessible. However, they did have reputations as good fishing ponds. It is noteworthy that two of the ponds most heavily fished (Pond 12 and Pond 45, contained many large bluegills. Both ponds were owned by farmers who were very conservative about giving permission to fish and most of the fishing was without permission. It is estimated that harvest at the six most heavily fished ponds would not exceed 65 pounds of fish per acre per year, and harvest at the other 12 ponds would not exceed 20 pounds per acre per year.

Turbidity of Ponds

No attempt was made to measure water turbidity caused by silt and clay, other than that its presence was recorded. Some of the turbidity was definitely due to roiling of the water, possibly by the activity of bullheads (Ponds 33, 39 and 46). In some cases turbidity was temporary, following rain and runoff from adjacent fields. In 12 cases, however, the turbidity appeared to be due to fine suspended clay that did not settle out during an entire summer. Many of these ponds were on eroded hillsides and were on heavy clay subsoils. Turbidity of a permanent or semipermanent nature affects the growth of plankton algae, and affects the feeding of bass by reducing visibility (Swingle, 1949). In the study ponds turbidity did not prevent the reproduction of bass but sometimes seemed to delay growth (Ponds 4, 17, 43) as evidenced by small two-year-old bass the second summer following stocking.

Vegetation in Ponds

Rooted equatic vegetation in ponds has been considered to be a deterrent to pond production of fish and to their harvest in many localities (Swingle,

1945; Edminister, 1947; Anderson, 1948; Ball and Tait, 1952). In our series of ponds the following species of aquatics occurred. common cattail *(Typha latifolia L.),* the pondweeds *(Potamogeton foliosus* Raf., *P. nodosus* Poiret and *P. spirillus* Tuckerm.), the water plantain *(Alisma subcordatum* Raf.), and the sedge *(Scirpus atrovirens* Willd.).

The common cattail was the most obvious aquatic plant about many of the ponds. In most ponds it occurred as only a few plants growing in a loose clump in water six to 12 inches deep. In a few ponds the cattails had apparently spread rapidly in a few years time until they occupied extensive portions of the shoreline out to a depth of three feet (Ponds 13, 28, 44).

The pondweed, *Potamogeton nodosus,* was the most common of the floating-leafed plants, occurring in eight ponds often with other pondweeds. In one pond (Pond 44) pondweeds formed an almost complete band along the shore to a depth of at least three feet, greatly hindering the use of the pond for bank fishing. It appeared that in this pond vegetation was not depressing the production of bluegills or the feeding of bass; both species were present in several age classes and the population was in balance.

Some algae were also prominent members of the pond flora. Filamentous algae formed small patches in a number of ponds and in one pond were present in large amounts each year. In Pond 5 the algal mat was so heavy by midsummer, 1949, 1950 and 1951 that it clogged the meshes in the 60-foot seine used to sample fish populations, and caused it to roll so that seining was ineffective. Spawning of bluegills was not eliminated by the mats of algae but as suggested by Ball and Tanner (1951) may have been reduced.

Algal blooms were common in the ponds. These blooms varied in color from deep green to dark brown and were probably made up of a number of species. Blooms were never present in waters containing large amounts of suspended clay.

Effect of Winter Kill on the Ponds

Death of fish when oxygen is depleted and concentrations of carbon dioxide build up beneath snow-covered ice is a common phenomenon in the North Central States (Greenbank, 1945; Bennett, 1948b; Cooper and Washburn, 1949). For the Marion County farm ponds information on occurrence of winterkill has been gathered from two sources: from farmers and others who observed numbers of dead fish in ponds following the breakup of ice, and from pond histories that indicate a sudden mass disappearance of bass, of bluegills, or of both. While in many cases there is no evidence as to the time of year when such fish disappeared, heavy mortality during the summer was observed by the pond owners only once (Pond 16) while winterkill was observed frequently. The chances of mass

mortality of fish being unobserved are probably greater in the winter than the summer.

It appears that fish populations in 31 of the ponds suffered winterkill (Table 6). In 15 ponds bass were eliminated but some bluegills survived; in two ponds the reverse was true, with bluegills winterkilled while some bass survived. The differential in mortality between these two species may represent a difference in tolerance to low oxygen levels (though Cooper and Washburn, 1949, found none), but more likely it may represent a difference in location within the pond during wintertime and ability of some individuals to locate and utilize pockets of water containing sufficient oxygen for survival.

Complete kills of both bass and bluegills occurred in 18 ponds. Thirteen of the 18 ponds also contained bullheads, and these always survived in some numbers.

Some ponds winterkill repeatedly, as is shown by the frequency of some pond numbers in Table 6.

TABLE 6.—*Known or suspected winterkills of fish in Iowa farm fish ponds*

Species eliminated by kill	Pond numbers
Bass, but not bluegills	3, 19, 19, 20, 24, 24, 29, 30, 32, 32, 35, 37, 40, 47, 48, 49, 49, 49, 50, 59
Bluegills, but not bass	3, 27
Bass and bluegills	9, 10, 11, 15, 16, 16, 16, 16, 20, 23, 27, 31, 35, 36, 39, 40, 41, 47, 49, 55, 56
Some bass and some bluegills	4, 15, 25, 37, 45

Winterkill is believed to be a major factor in the lack of population balance and success of Iowa ponds. The population remaining after an incomplete kill is often very different than that present before, and the change is usually unfavorable for angling (Bennett, 1948a). Of the ponds which winterkilled, one-half had been listed as muddy with colloidal clay, and one-third were known to have had low water levels going into the winter season.

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A SIMPLIFIED ROTARY FISH SCREEN AND AN AUTOMATIC WATER GATE[1]

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ABSTRACT

A simplified, rotary fish screen and an automatic water gate have been developed for use in streams or hatchery raceways. This self-cleaning screen is designed to replace stationary, vertical screens which become plugged with leaves, sticks, and other water-borne debris and require periodic cleaning in order to prevent water level fluctuations in raceways. It is of simple construction, operates for long periods, and is readily portable. It is not designed to replace large-capacity, gear-driven rotary screens.

The gate is used in conjunction with a gear-driven rotary screen, and is designed to open automatically during floods and pass water through the screen and to close automatically and seal off the screen when the water recedes to a normal level.

INTRODUCTION

Rotary fish screens have been used to carry excess water past fish traps at the Michigan Department of Conservation Hunt Creek Fisheries Experiment Station since 1949. These gear-driven screens designed by J. D. Alexander are similar to the Saunders inner-drive rotary fish screen described by Leitritz (1952a). Fish screens used in California were described by Wales (1948), Wales, Murphey, and Handley (1950), and Leitritz (1952a and b). Rounsefell and Everhart (1953, pp. 197-210) gave general descriptions of the types and uses of fish screens: Carbine and Shetter (1953) described the use of a rotating screen with a weir in Michigan; John (1954) proposed a spaced-disc type of fish screen; and Whalls, Proshek, and Shetter (1955) touched on some limitations of the Michigan gear-driven screen.

The gear-driven screens used at Hunt Creek are well suited for passing water in the Station's main stream where they are permanently installed, but operate only during periods of high water. They are not suited for use in raceways because constant operation results in frequent breakdowns and high maintenance costs. Also, special lifting devices are required to handle these heavy pieces of equipment. The simplified rotary screen (Figs. 1 and 2) described here is not intended to replace the gear-driven one, but is designed to replace the vertical screens in the Station's

[1]Contribution from the Institute for Fisheries Research.

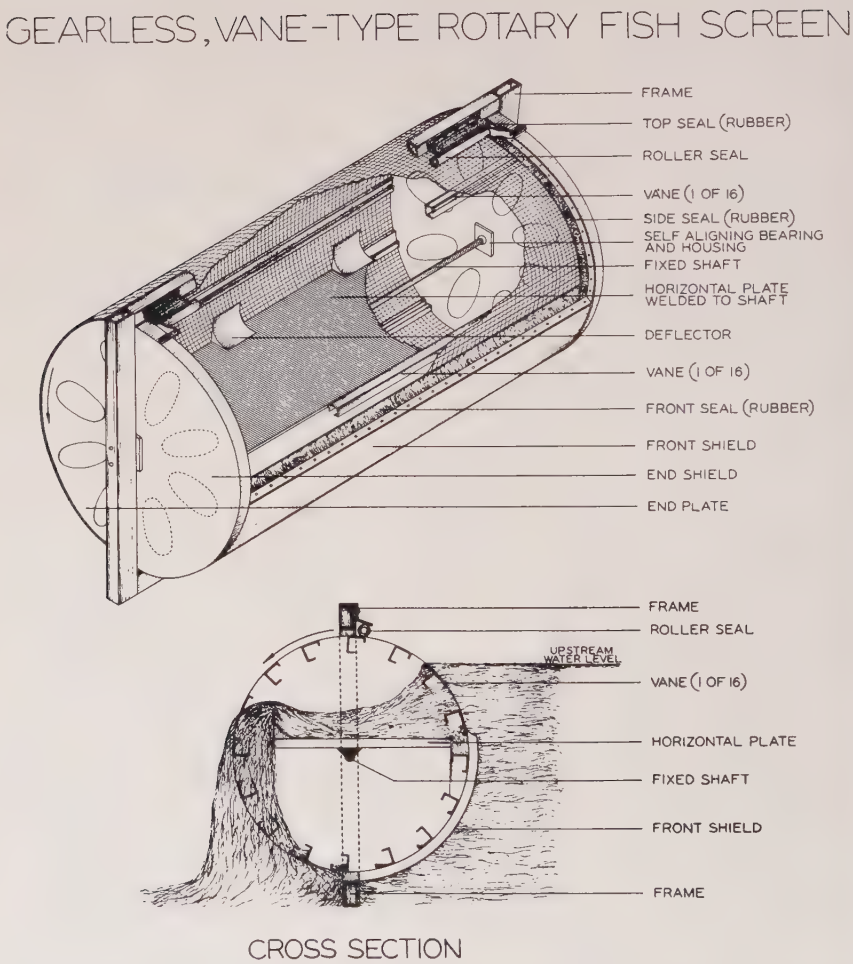


FIGURE 1.—Construction details of gearless, vane-type rotary fish screen developed in raceways at Hunt Creek, Michigan.

raceways where the volume of water flow can be regulated with a by-pass, and where a portable, lightweight, easily maintained screen is desirable. Vertical screens are rapidly clogged with debris, which disrupts the normal flow and results in unnatural stream conditions in the raceways.

The automatic water gate (Figs. 3 and 4) was developed to be used with the gear-driven rotary screens. The gear-driven screens are used only during high water; they are not used during periods when water levels in the main stream are normal (normal discharge is 23.2 c.f.s.). Prior to the development of the automatic water gate the screens were sald off by solid, framed, sheet-steel gates placed in slots in the bulkhead upstream from the rotary screens. When there was a possibility that the fish traps would be flooded because of melting snow, heavy rains, beaver dam breakage, or other causes, a man was dispatched to remove the solid gates to allow excess water to pass through the rotary screens. To avoid flooding of the fish traps and loss of fish, gates had to be removed when high water came, night or day, fair weather or foul. The water gate is designed to open automatically when the water rises to a determined point above normal, and close automatically when the water level recedes to a normal level. The rotary screen operates only when the gate is open.

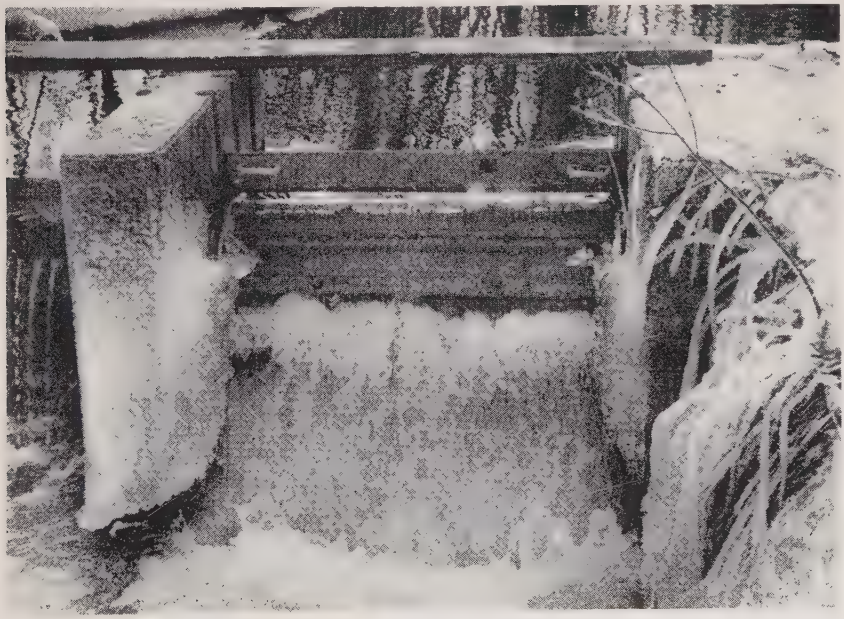


FIGURE 2.—Upstream view of the 12-vane model of the simplified rotary screen, showing the position of a vane filling with water and the fall (16 inches) required to operate the 24-inch diameter revolving drum.

Simplified Rotary Screen

General Description

The simplified rotary screen is activated by water that passes through its upper one-half on the upstream side, over the horizontal plate, and into the fixed vanes. The water retained in the vanes on the downstream side causes a torque that revolves the screen. Deflectors are placed on the horizontal plate to cause the vanes to fill with water before they reach the shaft level, thus adding to the revolving force. The vanes also serve as driving paddles at high water levels. A full-scale model (Fig. 2) was in operation for 814 hours in the Station's raceways, and for 215 hours in a raceway at the Wolverine Trout Rearing Ponds, Wolverine, Michigan. Performance was satisfactory at both locations. With the upstream water level about five inches above the shaft, the screen turns at 11 revolutions and passes 720 gallons of water per minute. Ice, leaves, grass, and small debris do not jam the screen; however, large debris will cause jamming when it wedges between the screen and the roller seal, but the simplified rotary screen will pass any object that will pass over the Michigan gear-driven screen.

The simplified rotary screen can be built for one-half the cost of the gear-driven screen, according to estimates made by engineers at the Michigan Department of Conservation Forest Fire Experiment Station, Roscommon, Michigan. If aluminum is substituted for steel in many of the parts, weight will be considerably reduced. The steel model is easily handled by two men.

Detailed Description

The design of the vanes is important to the proper functioning of the screen. Calculations must be made to insure that the torque exerted by the weight of the water in the vanes on the downstream side is greater than the torque exerted by the water pressure against the vanes and screen on the upstream side, otherwise the screen will revolve in the upstream direction or not at all. Also, allowance for friction from bearings and seals must be made. If few, large vanes are used, an undesirable pulsating action results and the screen is subject to jamming caused by reduced torque and slow rate of revolution at the ebb point of the pulse. Reduced torque and slower revolution result when the large, widely spaced paddles reach a position where one (or more) paddle is obstructing the flow of water on the upstream side of the screen, thereby reducing the water flow over the horizontal plate and into the vanes on the downstream side. It is the reduced volume and weight of water in the vanes at the ebb point that reduces the torque and rate of revolution. Twelve vanes were tried first (as in Fig. 2), but because of pulsating motion these were replaced with 16 smaller vanes designed to allow the same volume of water to pass

through the screen. The vanes must be shaped to hold a maximum amount of water on the downward swing, yet empty rapidly as they begin their upward movement. The vane design shown in Figure 1 is satisfactory.

The shaft is non-rotating, and is secured to the frame by set-screws; the horizontal plate is welded on top of it. The end-plates revolve on the shaft on self-aligning bearings. A fall of 16 inches is required for end-plates having 12-inch radii.

The front and side shields serve to bring the upstream water level up to the shaft level; and, with the horizontal plate, serve to direct the water into the vanes on the downstream side of the screen. The shields are welded directly to the frame and must be constructed so as to clear the bulkhead when the screen is in place in the keyways. The side shields also serve as a barrier to the passage of fish, so if the frame fits securely in the keyways, the side shields may be separated from the bulkhead without loss of fish. The water exerts considerable force against the shields so they must be braced to prevent them from being pressed against the screen and the end plates.

The purpose of the seals is to prevent the loss of fish. The front, side, and top seals are made from heavy-duty inner tubes. The roller seal is made of metal tubing covered with heavy duty reinforced rubber hose. In operation, the roller seal lifts on end hinges to pass debris between it and the revolving screen. The roller seal and the top seal are designed to prevent the loss of fish should the water level rise above the upper frame. Where possible, a framed vertical screen should be placed in the keyways above the rotary screen.

The rotary screen used at Hunt Creek is contained in a concrete bulkhead 4 feet by 4 feet by 8 feet. Each keyway is 2 inches deep. The rotary screen outer frame is 51.5 inches long and 31 inches high. The revolving cylinder is 48 inches long and its diameter is 24 inches. The dimensions of the vanes (Fig. 1, cross section) are: narrow lip, 0.5-inch; screen side, 2 inches; vertical side, 2 inches; wide lip, 1.25 inches; length, 47.5 inches. The horizontal plate is made of sheet steel framed with 0.25-inch angle steel. The shaft is 0.620-inch solid, steel rod.

Automatic Water Gate

General Description

The automatic water gate is a barrier, placed vertically in a bulkhead, and at right angles to the stream. It does not swing on hinges but turns on a horizontal shaft, and when open is in a position roughly parallel to the stream surface, permitting water to flow past it. The gate is designed to take advantage of the fact that water pressure on an immersed vertical surface varies widely, and increases with depth (Randall, Williams, and Colby, 1929, pp. 107-126). The gate is designed to stay closed at normal

water levels, when the force, resulting from water pressure, against the portion of the gate below the shaft is greater than it is against the portion of the gate above the shaft. The shaft must be placed below the center of the gate because the position of the shaft (fulcrum) determines what force (water level) will be required to keep the gate closed, or to open it when the water level rises. The gate opens when the increased force, resulting from higher water levels, against the gate above the shaft exceeds the force against the gate below the shaft. If the shaft were centered, forces below it would always exceed those above it and the gate would remain closed at all water levels.

Counterweights are used to close the gate when water level returns to normal after a flood. As the water recedes, and only a small amount is passing over the gate (weight of water on gate is reduced), the weights cause the gate to shut. Water pressure against the lower portion of the closing gate assists in the closure.

Detailed Description

Proper dimensions of the gate are dependent upon the width of the bulkhead, water discharge, and permissible fluctuations in water level. The height of the gate and position of the shaft are determined from calculations. A shallow gate works best where tolerable water fluctuations are small, and a deep gate works best where greater fluctuations in water level are permissible and large amounts of water must be passed. The

Table 1.—*Computations used to estimate the water level at which a 15- by 44-inch gate will open with the shaft (fulcrum) centered 3.5 inches above the gate bottom.*

Points on gate below surface of water (feet)	Force on gate resulting from weight of water[1] (poundals)	Water level above shaft (feet)	Forces acting to close gate (poundals)	Forces acting to open gate (poundals)
0.08	4	0.00	37	0
0.17	8	0.13	51	8
0.25	12	0.21	65	18
0.33	15	0.29	78	31
0.42	20	0.38	92	49
0.50	23	0.46	106	70[2]
0.58	27	0.54	119	96
0.67	31	0.63	133	125
0.75	35	0.71	147	158[3]
0.83	39	0.79	160	195
0.92	43	0.88	174	236
1.00	47			
1.08	51			
1.17	55			
1.25	59			

[1]0.08 ft. x 0.08 ft. x 3.67 ft. x 62.4 lbs./ft.^{3} x 32 ft./sec.^{2} x height.
[2]The gate is adjusted in the bulkhead so normal water level is about 0.42 foot above the shaft.
[3]The gate opens when the water level rises about 0.67 foot above the shaft.

gate here described is 15 inches high by 44 inches wide. The shaft is centered 3.5 inches above the gate bottom. It is designed to operate with the normal water level 5.0 inches above the shaft. It opens when water level reaches a point 8 inches above the shaft, and closes when flood waters recede to a point 1.5 inches above the shaft. Force required to open the gate is determined by using data such as are included in Table 1, plus calculating added force needed to overcome closing torque due to friction and the suspended counterweights. At normal water level the gate is kept closed because the force of 106 poundals against the 154 square inches (3.5 by 44 inches) of area below the shaft is greater than the force of 70 poundals against the 242 square inches (5.5 by 44 inches) of area above the shaft.

To eliminate as much friction as possible the shaft rotates on self-aligning bearings—this is especially important to the proper closing of the gate where counterweights should be kept to a minimum. The shaft is centered laterally in the inner frame to keep the forces caused by the weight of the closed gate perpendicular to the center of the shaft.

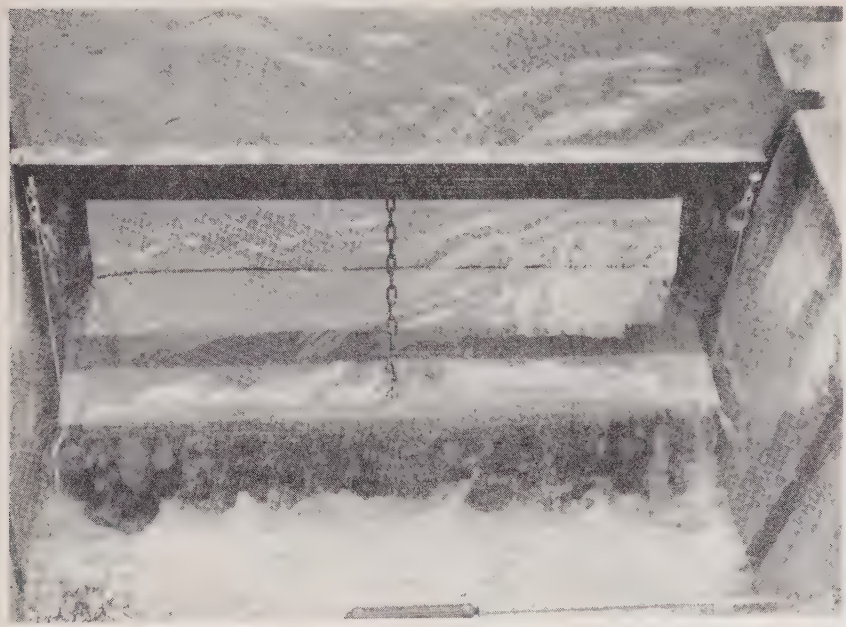
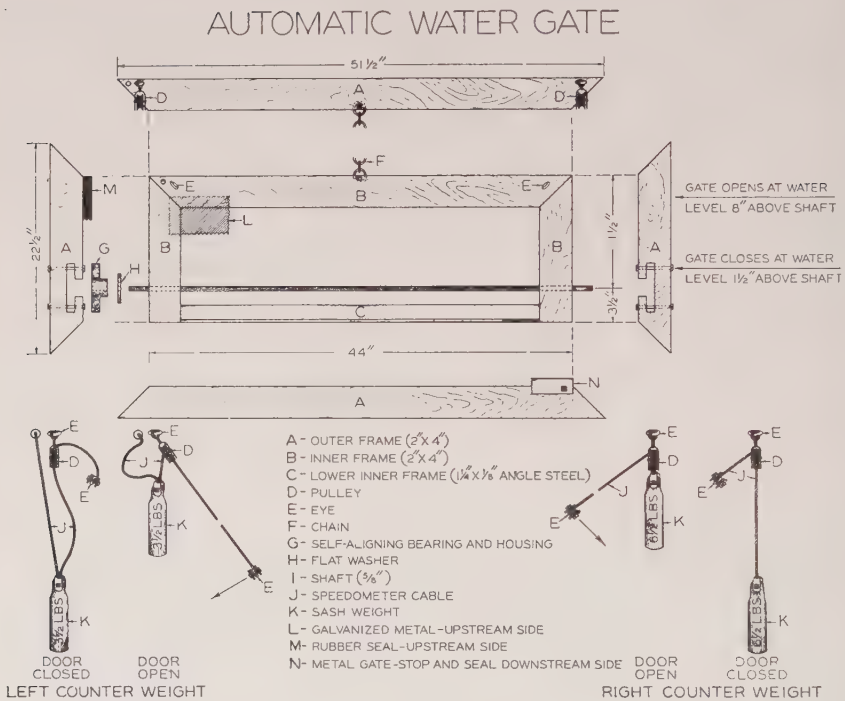
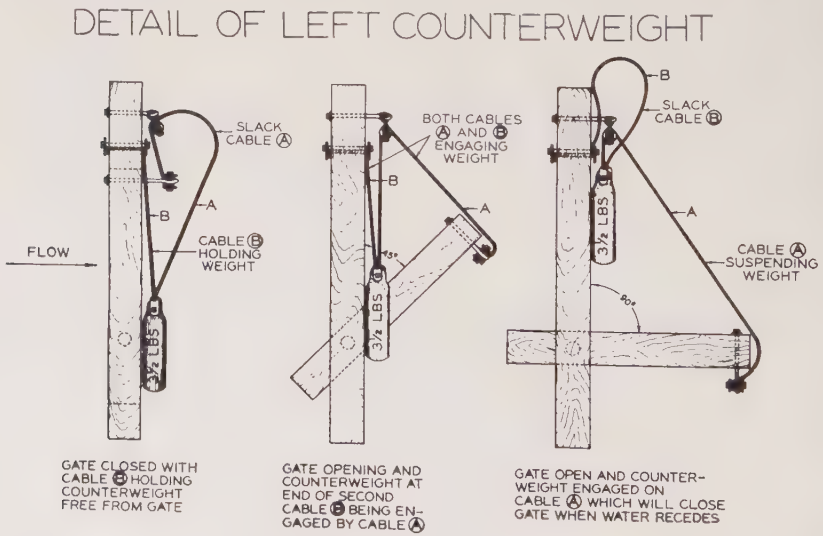


FIGURE 3.—An automatic water gate in the full-open position, showing the open gate, and both weights engaged to close the gate when the water level recedes to normal—this gate is almost at the closing point as will be noted from the slack chain.





FIGURES 4A and 4B.—Construction details of automatic water gate used to pass flood waters at Hunt Creek, Michigan; Figure 4A above and 4B below.

The counterweights used to close the gate must be heavy enough to overcome the weight of the gate above the shaft (acting to hold the gate open) and friction. Action of the counterweights is supplemented by the weight of the gate below the shaft (acting to close the gate).

If both counterweights are suspended directly to the gate as the right counterweight in Figure 4A, a greater force (necessitating a higher water level) is required to open the gate. To overcome this undesirable feature the left counterweight is connected to a second cable which is attached to the outer frame. The left counterweight is disengaged when the gate is closed. Operation of the left counterweight is illustrated in Figure 4B. With a closed gate and a rising water level, only the right counterweight is resisting the force that acts to open the gate; when the water level rises to the opening point on the gate, the gate swings to the one-half open (45 degrees) position, and cable A engages the left counterweight and the gate continues to open to the full-open position. Both counterweights act to close the gate when the water recedes. When the gate reaches the one-half closed (45 degrees) position, the left counterweight is disengaged from cable A and is engaged by cable B, and the gate continues to close to the full-closed position. No counterweights are necessary if the gate is closed manually. At Hunt Creek, only the left counterweight has cable B attached, but, if necessary, both counterweights could be attached to a second cable to permit the gate to open at a lower water level, and thus decrease the over-all water level fluctuation.

If the gate is made of wood, heavier counterweights must be used to overcome the buoyancy of the bottom board before the gate will close properly. This buoyancy may be greatly reduced either by constructing the bottom cross piece of the gate of angle steel (Fig. 4A) or by constructing the entire gate frame of welded angle steel. The latter method not only reduces buoyancy to a minimum, but also reduces the total weight of the gate, and thus reduces the size of the counterweights required. The gate framed at top and sides with wood and with angle steel at the bottom is simple to construct and low in cost. Wood and steel should be used in pilot models until all specifications are determined, and then a more permanent steel gate built.

A length of chain holds the open gate perpendicular to the outer frame to allow the greatest area for water passage.

Acknowledgments

The authors wish to express their appreciation to Messrs. Steve Such and Gil Stewart, engineers, who offered valuable criticism of the simplified rotary screen, to Max Bradley who prepared blueprints and preliminary drawings, and to William L. Cristanelli who prepared the final drawings of the screen and the water gate.

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Part 2
Symposium On The Great Lakes

[REPORT OF COMMITTEE ON INTERNATIONAL RELATIONS]

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SYMPOSIUM

On The

GREAT LAKES

INTRODUCTION

RICHARD CROCKER

California Department of Fish and Game, Sacramento.

This year the Program Committee thought it would be desirable to present a symposium on a subject of prime interest to the area where the meeting was held rather than a report of the usual type. It was decided to take as the subject the Great Lakes since the management of these waters is of great importance to both United States and Canada and because fisheries in the Great Lakes are now under the jurisdiction of the newest of the several International Fisheries Commissions by which fisheries matters of our countries are closely tied.

Such International Fisheries Commissions are setting the pace on the world scene by the management and conservation of fisheries; management and conservation that is international in scope. Pioneering work along this line was done by the International Pacific Halibut Commission and the International Pacific Salmon Commission. Since the war there has been a growing realization of the significance of international commissions and the Tripartite International North Pacific Fisheries Commission has been organized and in this Canada and the United States have joined with Japan in an attempt at fisheries conservation in the northern Pacific. At about this same time the 10-member International Commission for the Northwestern International Fisheries was formed, and again Canada and the United States are signatories. The United States is also a member with Costa Rica and Panama of the International Tuna Commission, which in waters far distant from here is doing a fine job. Whaling matters are taken care of by the International Whaling Commission.

For many years there has been a growing realization that some of the problems on the Great Lakes, such as will be discussed by the panel, could be solved through similar international cooperation.

ARTIFICIAL PROPAGATION IN THE MANAGEMENT OF GREAT LAKES FISHERIES

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Abstract

No positive evidence has been found to suggest that artificial propagation has ever been successful in significantly increasing the yield of a native species in the Great Lakes.

The possible contribution of artificial propagation to the populations of Great Lakes fish has been investigated in three ways: by looking for correlations between the numbers of fry planted and the size of the commercial catch in the years when the resulting individuals would have entered the fishery in the greatest numbers; through experiments in which fry are planted only in alternate years and the relative strengths of year classes in appropriate number of years later determined; through experiments in which marked lake trout fingerlings are planted and the number subsequently caught recorded. Neither of the two types of experiment has been carried on long enough to yield decisive results.

From a consideration of the history of some unusually successful year classes and some unusually unsuccessful year classes it is concluded that the size of a year class is determined by conditions affecting hatching and survival rather than by the size of the spawning stock, which is usually adequate to produce large populations if environmental conditions are favorable. Far too much confidence has been placed in the planting of hatchery-reared fish as a means of maintaining or increasing fish populations.

The early fish-culturists were spectacularly successful in selling the general public as well as the commercial fisherman and angler on the idea that through fish culture our waters could be made to produce almost unlimited supplies of food and game fish. Wood (1953) quotes Dr. Theodatus Garlick (1857) as saying "It should not be surprising that the subject [fish culture] is attracting the attention of some of the best minds in our country; more especially when we consider the impoverished condition of our rivers and streams, many of which are susceptible of being inhabited by innumerable salmon and trout and since a replenishment is now no longer problematical." Samuel Wilmot, father of Canadian fish culture wrote in similar vein (1870): "A repetition of this process [planting artificially hatched salmon in streams emptying into Lake Ontario] for a few years, aided by judicious enactments for their preservation and protection would undoubtedly soon replenish and restock the waters of Lake Ontario with salmon."

The predecessor of the American Fisheries Society, the American Fish-Culturists' Association, in 1872 urged Congress to enlarge the duties of the Fish Commission to include the propagation of fish. For many years following the initiation of hatchery work, artificial propagation and marine investigations were the major functions of the Fish Commission. As Wood points out, artificial propagation was "the one strong issue which was relatively uncontested for more than 70 years and which has been the foundation of fish management for an even longer period." By 1899 the total Federal (U.S.) production of eggs, fry and fish exceeded 1 billion and continued to increase until 7 billion was reached (Wood, 1953). The Great Lakes received their share from this stupendous effort.

So great was the confidence in the efficiency of planting hatchery-reared young in maintaining the fisheries that lack of evidence in support of such confidence was overlooked until quite recently. The attitude appears to have been that so certain was it that artificial propagation was effective in maintaining the fisheries that there was no need to consider the possibility of the proposition being untrue. For instance in 1894 in a discussion of Great Lakes fisheries it was stated that, although the statistics showed that in nearly every lake the catch of whitefish the species having the greatest interest to the fish-culturist had decreased since 1885, "no well-informed person, however, will argue from this that fish culture in the Great Lakes is a failure.' Rep. U. S. Fish Comm., 1892, App. iv; p. 458).

It was not until about 1925 that doubt began to be expressed publicly. In that year Koelz (1926) wrote, "Unfortunately there are no criteria by which we may judge the effect of propagation in the Great Lakes . . . The fact that there are areas where whitefish are said to have increased in recent years without the aid of artificial propagation and the fact that the sucker, perch, sauger, blue pike, chubs and herring, in spite of the persecution they have sustained, do not make a worse showing in the statistics than the carefully fostered whitefish and trout, at least justify an attitude of skepticism toward the enthusiastic claims of some of the propagationists."

In the case of trout planted in streams it has been possible to demonstrate beyond reasonable doubt that, "Recoveries from experimental plants in streams of brook, rainbow and cut throat trouts have indicated an average recovery from fall-planted fingerlings of less than one per cent" (Holloway, 1945). Demonstration of this fact has been possible because the planted fish can be marked so that they can be recognized when subsequently caught. In the case of most commercial species planted in the Great Lakes—whitefish, lake herring, and walleye, the fry are planted at such a small size that marking is impossible.

Three methods have been used to determine whether the planting of hatchery-reared young in the Great Lakes has contributed significantly to th production of fish of commercial size. The first of these methods has been to determine whether any correlation exists between the number of

planted young and the relative success of the corresponding year classes in the fishery when the young have grown to the size at which they enter the fishery.

As Hile (1937) has pointed out, belief in the value of hatcheries in increasing production arises in many cases from a failure to relate production properly to plantings. For instance, the "Great Lakes Fisherman" in discussing the increase in the abundance of the walleye in Lakes Huron and Michigan in the years 1932-1935, said, "it is significant for the fishermen to note that the amount of fish produced is directly proportional to the number of spawn planted each preceding year." This statement implies that the fry planting of one year leads to production of commercial fish in the year following, which is absurd. Hile showed that when an attempt was made to find a correlation between the number of fry planted and production and abundance in the year when the resulting fish would have reached commercial size no such correlation was found.

Other attempts to find a correlation between the numbers of artificially reared young planted and subsequent production of fish of commercial size have also failed. For instance, Van Oosten (1942) was unable to find any relationship between the plantings of fry and production of whitefish in Lake Erie. The data covered a period of 21 years (1920-1940). Comparison was made between the number of fry planted and the whitefish catch 3 years later. The interval of 3 years was selected since it was found that 3-year-old fish (in fourth summer of life) made up, on the average, approximately 60 percent of the number of legal whitefish taken by commercial fishermen in Lake Erie. Four-year-old fish ranked second in abundance. Few whitefish older than 4 years or younger than 3 normally occur in the commercial catch. If the plantings of fry were effective in maintaining the whitefish catch a change in the size of plantings (136 million to 557 million) should be reflected in a corresponding change in the size of the catch 3 years later. No evidence of any such relation was found in the statistics. Van Oosten concluded that "whitefish production in Lake Erie is not dependent on or noticeably affected by the planting of fry."

Failure to find a correlation between the number of whitefish fry planted in Lake Ontario and the commercial production has been reported by Lapworth (1956). The area for which plantings and commercial production were compared was the Bay of Quinte region near the eastern end of the lake. This is by far the most productive area of Lake Ontario so far as whitefish is concerned.

Plantings and production were compared for the years 1924-1947. Since in this area whitefish do not enter the commercial fishery in numbers until they are 5 years old when, on the average, 47 percent of the catch is of this age, the catch was compared with the number of fry planted 5 years previously. If plantings significantly affected production, large

plantings should, on the average, be followed by larger production than small plantings. No such correlation could be found. As a matter of fact the largest plant, 208,000,000 in 1927 was followed in 1932 by the smallest catch of the entire period.

Similarly Carlander (1945) was unable to find any relation between abundance of the year classes and number of walleye fry planted in the Lake of the Woods, Minnesota. He noted that the year in which the smallest number of fry were planted produced the most abundant year class.

A weakness in this method of attempting to assess the value of fry planting is that there is no assurance that commercial catch accurately represents actual abundance in the water. However, this is no reason to believe that the catch is not *usually* at least a rough measure of abundance so that a small catch is a reflection of less abundance than a large catch, especially for such a valuable species as whitefish the fishery for which is vigorously prosecuted.

The second method of attempting to determine the value of hatcheries has been through planting only every other year. The theory on which these experiments are based is that if planting is efficacious, year classes reinforced by artificial propagation should usually be stronger than those produced only by natural means.

In Alberta such an experiment was carried on over a period of 10 years in seven lakes (Miller, 1952). In each lake eyed whitefish eggs were planted in some years and not in others. By using several lakes of different sizes it was expected that the effect of meteorological conditions would be minimized. The number of eyed eggs planted varied from 1 to 89 million depending on the size of the lake (12 to 462 square miles).

If planting increased production significantly the number of 5-year-old fish in a lake planted in 1941, but not in 1942, should have been greater in 1946 than in 1947, again greater in 1948 from the 1943 plantings and less in 1949. In another lake not planted in 1941 but planted in 1942 the yield of 5-year-old fish should have been poorer in 1946 but better in 1947.

Consideration of the relative strengths of the year classes in the lakes included in this experiment led to the conclusion that year-class strength had been completely unaffected by plantings from the hatchery on lakes where a spawning population existed.

In Lake Ontario a similar experiment has been under way since 1944. Beginning with 1945 no whitefish fry have been planted in the odd-numbered years (1945, 1947, 1949 . . .) while plants have been made in the even-numbered years (1944, 1946, 1948 . . .). The possible effect of plantings in increasing production is being tested by determining the percentage contribution of individual year classes to the population as

sampled by the commercial catch. The results of this experiment are not yet available.

The third of the methods tried in attempts to determine the possible value of planting hatchery-reared young in the Great Lakes was through the planting of marked lake trout fingerlings. This is comparable to the method that has been used with such apparent success with brook, rainbow, and brown trout planted in streams.

This lake trout planting experiment is a cooperative project organized in 1941 by a Great Lakes Trout Committee on which the States fronting Lakes Michigan and Superior were represented as well as the U. S. Fish and Wildlife Service. In 1946 Ontario became a member of the committee, which since has been incorporated into the Great Lakes Fishery Committee.

The original plans were to plant in Lake Michigan as many lake trout fry and fingerlings as possible in 1944, 1945, and 1946, and to fin-clip at least 10 percent of the fingerlings in each of these years, but to permit no planting of lake trout in Lake Michigan in 1947, 1948, and 1949. Any lake trout fry or fingerlings produced from Lake Michigan in 1947-49 were to be planted in Lake Huron or in inland waters. At least 10 percent of the fingerlings planted in Lake Huron were to be fin-clipped.

The percentages of hatchery and non-hatchery (wild) lake trout of commercial lifts of gill-nets and other gear were to be determined at different localities on Lakes Michigan and Huron and the thoroughness and accuracy of reporting by fishermen were to be checked. The plans also included study of factors affecting the results of such a research including the occurrence of naturally missing or deformed fins, the extent of fin regeneration, and the effect of fin-clipping on survival.

The results of recoveries of marked lake trout from Lake Michigan up to and including 1951 have been reported by Cable (1956). Of 411,394 marked fingerlings planted only 1,319 have been reported as captured, a return of 0.32 percent. Most of these were under the legal commercial size of 1½ pounds. To what extent the depredations of sea lampreys have affected the results of the experiment is impossible to say.

Experiments planned to test the value of planting hatchery-reared lake trout are being carried out in Lake Superior as well. Duplicate lots of marked yearlings are being used, one lot being planted in the fall, the other in the following spring. The first planting under this programme was made in the fall of 1952.

It is much too early to draw any conclusions from the returns but it is to be feared that lamprey depredations will interfere with the drawing of any dependable conclusions as to the survival to be expected should the lamprey be brought under control.

The Province of Ontario has also carried out experiments in which marked lake trout fingerlings have been planted in Lake Superior and in Lake Ontario. Plantings in Lake Ontario have been in conjunction with similar work by the State of New York. Lake trout yearlings have also been planted in South Bay, Lake Huron since 1949. As in the case of the other experiments with lake trout, the Ontario plantings have not yet been in progress long enough to justify the drawing of definite conclusions.

The failure of artificial propagation to produce any demonstrable increase in the yield of Great Lakes fisheries is probably to be explained on the assumption that in large lakes enough adults escape fishing to produce all the young which can survive under the conditions obtaining in most years.

This situation is illustrated by the findings of the Charlotte County lakes investigation in New Brunswick. In an experiment extending over a period of nearly 10 years, 27,730 hatchery-reared fingerling brook trout, marked so that they could be recognized when caught, were planted in eight lakes. Of these planted trout only 30 (0.1 percent) were taken by anglers while 698 or 23 times as many naturally spawned trout were caught (Smith, 1952). This experiment was carried out because of the poor fishing in the lakes. It was desired to determine to what extent angling could be improved through artificial propagation. The experiment proved that the few trout in the lake produced practically all the young which conditions in the lakes would support. It is uncertain that the yield was increased by even the 30 hatchery-reared fish caught. It is possible that some or all of these survived at the expense of 30 naturally-spawned fish which lost out in the struggle for existence in a population of young too large for the habitat.

Even in fairly heavily fished trout streams enough spawners escape capture to produce all the young which can find a living. This fact is proved by the results of numerous experiments in many States in which it has been shown that on the average less than 2 percent of planted fingerlings survive to the point of contributing to the angeler's catch (Wis. Cons. Dept., 1954). The most economical way of giving anglers more trout than a stream will produce naturally is to plant legal-sized fish a few days before they are to be angled. This procedure is comparable to stocking a pasture with fat cattle a few days before they are to be marketed. Stocking with more young cattle than the pasture would support in the hope of increasing output would lead instead to their starvation.

Consideration of the history of some unusually successful and some unusually unsuccessful year classes of whitefish, lake herring, and walleye in the Great Lakes indicates that it is not the size of the adult spawning stock which determines the size of the resulting population.

Scott's (1951) study of the very large population of lake herring in Lake Erie in 1945 and 1946 showed that well over 90 percent of the commercial catch consisted of fish from the 1943 spawning (1944 hatch) and that this was probably one of the smallest spawnings on record. On the other hand, the relatively enormous spawnings of 1945 and 1946 resulted in the production of very small year classes.

Another example of the same phenomenon was the occurrence of unusually large numbers of walleyes in Green Bay, Lake Michigan in the late 1940's (Hile, 1955). In this case, too, at least 90 percent of the commercial catch was made up of a single year class, hatched in 1943, and came from a relatively small spawning stock. When conditions are favorable for hatching and survival even a small spawning can produce a relatively enormous population whereas, if conditions are not favorable, even large spawnings will produce small numbers of progeny. This explains why planting even large numbers of artificially reared fry can result in a small year class while a huge year class can result from a small spawning even in the absence of any planting. All evidence suggests that the success of a year class in the Great Lakes is determined by the conditions affecting hatching and survival rather than by the size of the spawning stock which is usually adequate to produce large populations if conditions are favorable.

In a few unusual situations, the size of the spawning population may be reduced to the point where it does not produce adequate numbers of young even under favorable conditions. Such situations are brought about when a population is wiped out, or nearly so, through winter kill, pollution, or some other catastrophe. The arrival of the sea lamprey in the upper Great Lakes appears to have led to the near extinction of the lake trout in Lakes Michigan and Huron. When such unusual decimating factors have been removed it almost surely will be advantageous and may prove necessary to hasten the restoration of a species by artificial propagation although, when favorable conditions are restored, even a very small stock will quickly restore a population because of the high biotic potential of most species of fish.

Another circumstance under which it might be advantageous to plant hatchery-reared fry is when natural conditions for hatching have been unfavorable but subsequent conditions for survival and growth are favorable.

Evidence for the belief that scarcity of eggs is seldom responsible for the failure of a year class has already been presented. Factors responsible for the failure of enough of the eggs to hatch and for the resulting fry to survive include: (1) conditions unfavorable for hatching: (2) physico-chemical conditions which result in the death of the fry; (3) lack of sufficient food of the proper kind, at the right time, and place for the

fry—competitors for the same food could result in reducing the supply for the species in which we are interested; (4) predation; (5) epizootics. The operation of any of these factors singly or in combination may result in the production of a weak year class in spite of adequate spawning.

It is not known how often the decimating factor or factors operate against hatching and how often against the survival of fry after a successful hatch. To plant artificially hatched young on the chance that natural conditions for hatching have been unfavorable but that subsequent conditions for survival—including physico-chemical, food, competitor, predator, and disease conditions—are all favorable for the young is taking a very long chance. The search for positive correlations between the size of the resulting year class and the number of fry planted indicates that it is rarely, if ever, that conditions unfavorable for a successful natural hatch have been followed by all of the factors necessary for survival and growth of the young.

In summary, it may be said that there is no positive evidence that artificial propagation has ever been successful in significantly increasing the yield of a native species in the Great Lakes.

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RECENT CHANGES IN THE DEEP-WATER FISH POPULATIONS OF LAKE MICHIGAN

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Abstract

The deep-water fish fauna of Lake Michigan consisted of lake trout *(Salvelinus namaycush)*, burbot *(Lota lota maculosa)*, seven species of chubs or deep-water ciscoes *(Leucichthys* spp.), and the deep-water sculpin *(Myoxocephalus quadricornis)*. Other species occupied the deep-water zone but were not typically part of the fauna.

Lake trout, burbot, and a well established commercial fishery held the chub population in somewhat of a balance until the sea lamprey *(Petromyzon marinus)* destroyed the lake trout and burbot. Released from predation, one species of chub *(L. hoyi)* increased until its abundance in 1955 was 347 percent of that in 1930-1933. It is the smallest and most slowly growing of the chubs in the lake. Other chubs were reduced in abundance (1954-1955 abundance only 37 percent of that of 1930-1932) by an increased fishing pressure and by sea lamprey predation which shifted to them when lake trout and burbot became practically extinct.

Selective destruction of the large chubs reduced the average length by 1.5 and 2.2 inches in the northern and southern portions of the lake, respectively, and practically eliminated two largest species *(L. johannae* and *L. nigripinnis)*. Chubs over 10 inches long made up 72 percent of the catches in 1930-1932, but only 21.5 percent in 1954-1955.

Introduction

The deep-water (below 25 fathoms) fish community in Lake Michigan, and in the other oligotrophic Great Lakes, is comparatively simple. Until recently this community was dominated by lake trout *(Salvelinus namaycush)* and burbot *(Lota lota maculosa)* as predators with seven species of deep-water ciscoes or chubs *(Leucichthys* spp.), and the deep-water sculpin *(Myoxocephalus quadricornis)*, as prey. Since Lake Michigan became ice-free less than 11,000 years ago there has been little time for other native fish to adapt themselves to the deep-water habitat or for many exotic species to enter the drainage. Principal species inhabiting shallower areas of the lake but often mingling with deep-water species are the lake herring *(Leucichthys artedi)* suckers *(Catostomus commersoni* and *C. catostomus)*, walleyes *(Stizostedion v. vitreum)*, yellow perch *(Perca flavescens)*, and whitefish *(Coregonus clupeaformis)*. Burbot are abundant in shallow as well as deep water, and a few lake trout and chubs are commonly found in shallower areas of the lake.

The movement of the sea lamprey into Lake Michigan and its explosive increase in abundance in the late 1940's (Applegate, 1950) added a new species that was to have a profound effect on the deep-water community. The sea lamprey spends most of its life (usually 4 or more years) in streams as a non-parasitic larva. After metamorphosis to the parasitic form it migrates to the lake, and spends 12 to 18 months feeding on fish before returning to streams to spawn and die (Fig. 1). The favored habitat during its parasitic existence is deep water and the favored food is the larger fish. This selection of larger fish probably is a matter of mechanical ease of attachment rather than preference; lampreys rapidly grow to a size at which attachment on small fish is impossible. Thus the lake trout and burbot, which had been practically free of predation, except from the fishery, were suddenly subjected to exploitation by a voracious predator. The large chubs which had grown beyond the size that could be eaten readily by lake trout and burbot were also no longer free from predation during the period when their reproductive capacity was at a maximum.

Although burbot had never been exploited heavily by man, the lake trout and chubs had long been the object of a brisk commercial fishery. The decline of the commercially exploitable lake trout under lamprey predation was easy to document (Hile, Eschmeyer, and Lunger, 1951) as was the subsequent near extinction of lake trout of all sizes (Eschmeyer, 1957). Burbot also are no longer taken in commercial nets in deep water, although they are still found in shallow-water areas. Despite the lack of supporting data, it is believed that the deep-water sculpins, free of predation by lake trout and burbot, and too small to be preyed upon by the sea lamprey have increased greatly in abundance. The chubs, however, suffered a more complex fate because they are represented by several

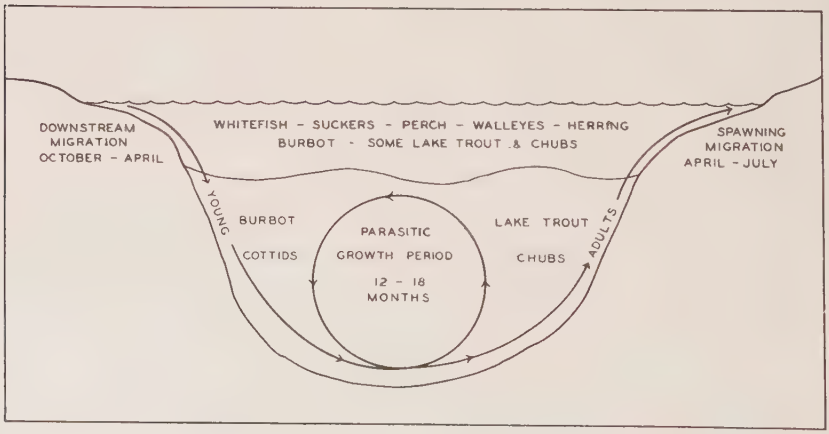

FIGURE 1.—Distribution of parasitic sea lampreys during their life in the Great Lakes contrasted to the general vertical distribution of the important species of fish.

species which when mature range from sizes too small for parasitic attachment by sea lampreys to sizes fully exploitable by the lamprey and the commercial fishery alike.

The commercial catch could not reflect accurately changes in the abundance of chubs. The disappearance of the lake trout, and the reduction in abundance of still other varieties by lamprey predation, combined to force the deep-water commercial fishermen to turn to chubs as the only plentiful fish consistently in commercial demand. Consequently, the production of chubs increased greatly as the catch of lake trout declined (Fig. 2). The abundance index derived from commercial catch reports increased slightly and fishing intensity rose sharply during this period of increasing chub production (Hile and Buettner, 1955). The increase in abundance may be only apparent, that is, largely attributable to the fishermen's keeping and marketing smaller chubs as the numbers of larger

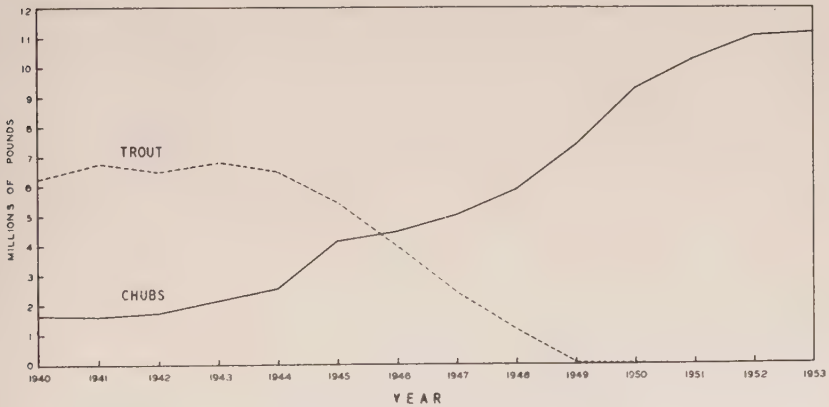

FIGURE 2.—Commercial production of lake trout and chubs in Lake Michigan showing the shift from trout to chubs as lake trout stocks declined.

ones decreased. Previously many smaller fish were not reported in catch records because they were neither landed nor marketed. The increased catch may also be attributed in part to the transition from cotton gill nets to the use of more efficient nylon nets in recent years.

I wish to acknowledge with deepest thanks the invaluable assistance of Stanford H. Smith in the preparation of this manuscript and the courtesy of John Van Oosten in authorizing my publication of summary data from the records of the 1930-1932 research from the *Fulmar*.

Biological Characteristics of Lake Michigan Chubs

Of the eight species of *Leucichthys* in Lake Michigan, the lake herring *(L. artedi)* inhabits the shallowest water. Small numbers are taken in the

deeper areas, the favored habitat of the other seven species. Thus, they are treated here as chubs although in the popular sense they are not considered as one of this group. Of the other seven species, two are relatively shallow-water forms *(L. hoyi and L. reighardi)*, three characteristically inhabit intermediate depths *(L. alpenae, L. johannae,* and *L. zenithicus)*, and two are predominantly deep-water forms *(L. kiyi* and *L. nigripinnis)*. *L. johannae* is also common in the deepest areas and all species are frequently found at depths outside their usual ranges.

The American Fisheries Society has assigned common names to the chubs but in the industry, names vary throughout the lakes and sometimes the same name may apply to different species in different lakes. Most fishermen do not recognize the full roster of species. Therefore, in sub-

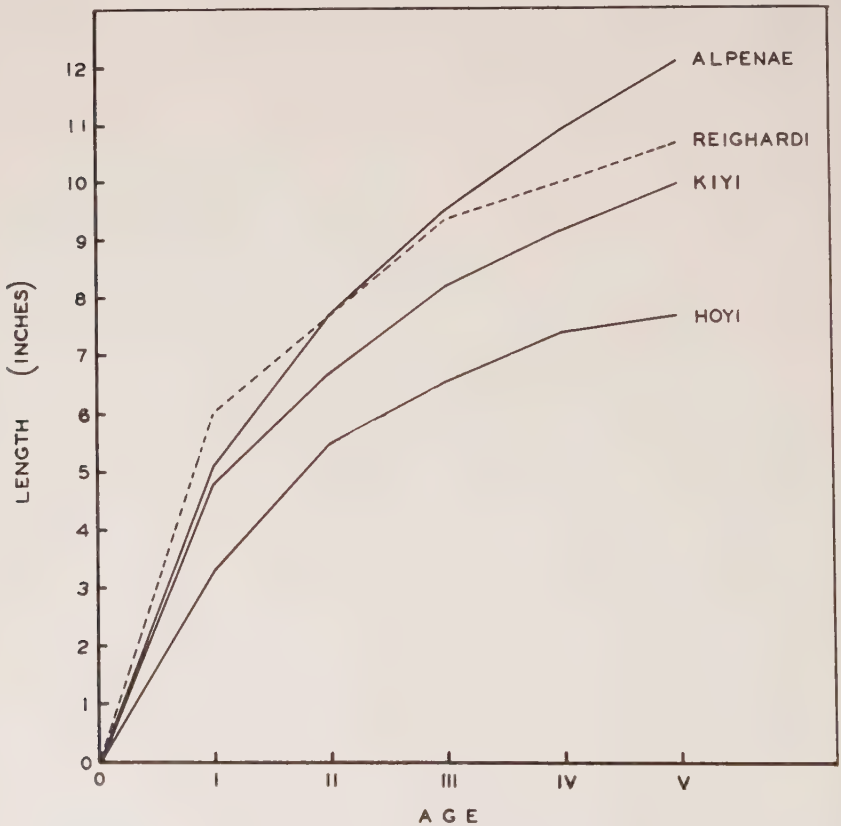

FIGURE 3.—Growth of Lake Michigan chubs (age-group V) for which life history data are available. See text for sources of data.

sequent discussions the various species will be designated by their specific name only to avoid any possibility of confusion. Some chubs could not be identified because physical differences between certain species are small and others because they were mutilated in capture. These fish are recorded in tables as unidentified.

Growth has been studied for four species of chubs from Lake Michigan (*alpenae,* Jobes, 1949a; *hoyi,* Jobes, 1949b; *kiyi,* Deason and Hile, 1947; *reighardi,* Jobes, 1943). The growth of each of these species is different (Fig. 3). Of particular significance, as will appear in later discussions, is the extremely slow growth of *hoyi.* Of the species not shown, *johannae* and *nigripinnis* are known from experience as the two largest chub species; *zenithicus* is much like *alpenae* in size and general appearance and is probably also similar in growth; and the growth of *artedi* in Green Bay (Smith, 1956) is intermediate to that of *alpenae* and *kiyi.*

Of the four species of chubs for which biological studies have been completed (*alpenae, hoyi, kiyi,* and *reighardi*) all reach normal maturity in their third and fourth years of life. This age at maturity may also apply to *artedi* (as it does in Green Bay—Smith, 1956) and *zenithicus,* but it is difficult to say whether it might hold for the much larger species (*johannae* and *nigripinnis*). If it is assumed arbitrarily that chubs become susceptible to lamprey attack and use by the commercial fishery at a length of about 10 inches, it is seen that all species except *hoyi* spawn only once or twice before reaching this size (Fig. 3), but that the average *hoyi* is nearly immune from attack through its fifth year. Thus *hoyi,* free from predation by lake trout, burbot, and lamprey, and little exploited at its younger ages by the commercial fishery, can reproduce more efficiently than any other species of chub.

The chubs feed almost entirely on small invertebrates (mainly *Mysis relicta* and *Pontoporeia hoyi*). Their main competitors for this food before and during the sea lamprey invasion were cottids (deep-water sculpins) and small lake trout and burbot (Fig. 4). In turn, the small chubs and cottids were consumed by the larger lake trout and burbot while the lake trout and large chubs were cropped by the commercial fishery. The sea lamprey entered this relatively simple food chain as an additional consumer of large chubs, lake trout, and burbot. Increased cropping of these fish lessened the competition for food between large and small chubs, and also reduced predation on small chubs and cottids. Ultimately, the lake trout and burbot were completely removed from the food chain, eliminating predation on small chubs and cottids. Furthermore, the demand of trout and burbot on the invertebrate food came to an end. Large chubs alone remained to support the sea lamprey and the commercial fishery (Fig. 4). Such a system obviously favors cottids and small chubs, particularly the slowly growing *hoyi.*

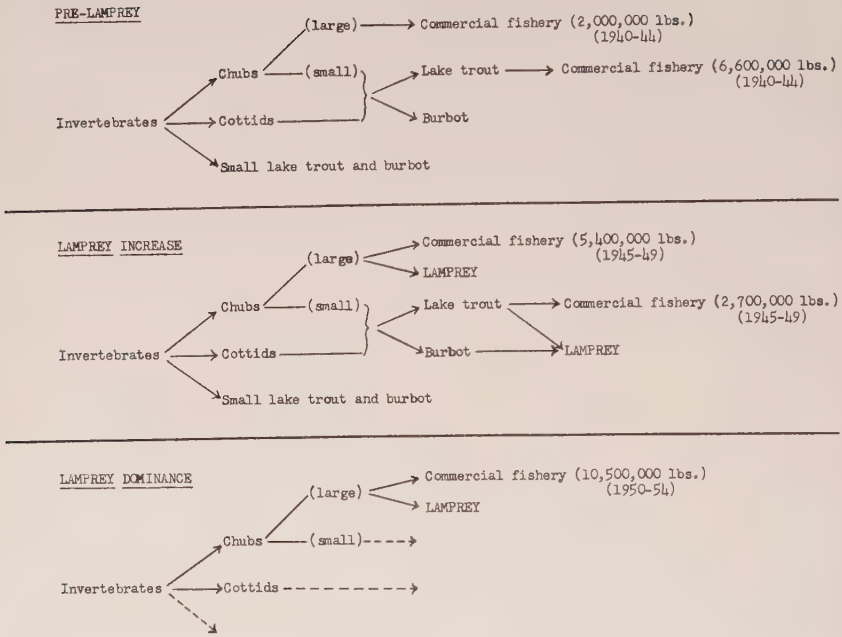

FIGURE 4.—Food chains of the deep-water fish of Lake Michigan before, during, and after establishment of the sea lamprey.

CHANGES IN THE CHUB POPULATION

The first evidence of a change in the chub population of Lake Michigan came when commercial fishermen complained in the early 1950's of large numbers of bloaters (their name for all small chubs—mostly *hoyi)* in their gill nets. Measurement of these changes has been possible because the U. S. Bureau of Fisheries research vessel *Fulmar* conducted studies in Lake Michigan in 1930-1932 (long before the sea lamprey invasion) during which extensive gill-net fishing was conducted and data were compiled on the size, abundance, distribution, and other characteristics of the various species of chubs. To obtain comparable records, the research vessel *Cisco* operated by the U. S. Fish and Wildlife Service fished gill nets of identical specifications during 1954-1955 at the same depths, locations (Fig. 5), and periods of the year as the *Fulmar*. Although analysis of the 1954-1955 data is not yet complete, the findings on abundance, species composition, and size are given here.

In 1930 and 1931 the *Fulmar* operated almost exclusively in the south and central portions of Lake Michigan and in 1932 it worked in the northern end (for details see Deason, 1932). The *Cisco* operated in the area from Manitowoc and Ludington south in 1954, and from these ports

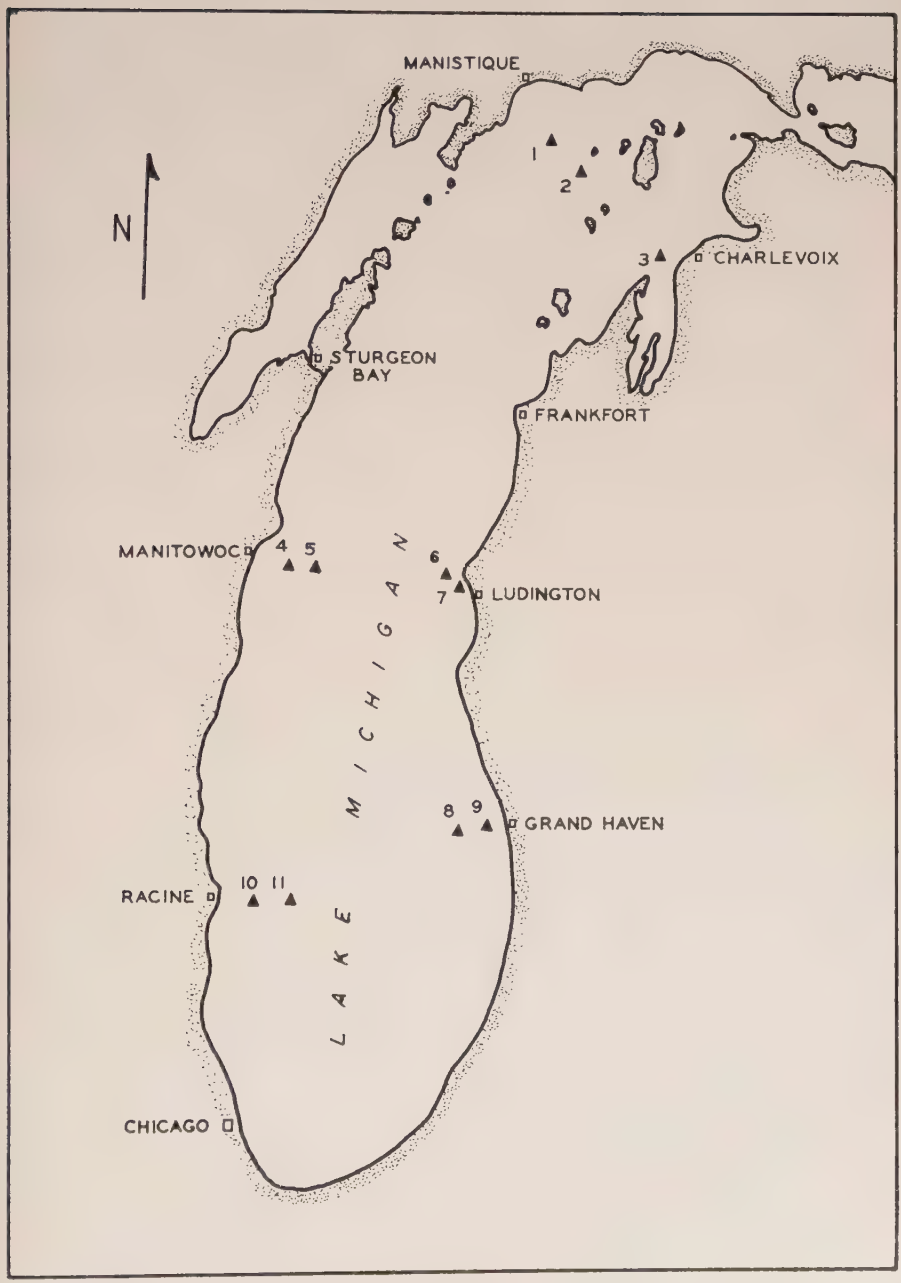

FIGURE 5.—Locations of gill-net stations in Lake Michigan where identical nets were set by the *Fulmar* in 1930-1932 and the *Cisco* in 1954-1955.

north in 1955. Standard gangs of gill nets used for comparisons between the two periods were made of linen. Each gang contained one net each of the following mesh sizes (stretched measure as manufactured): 2⅜, 2½, 2⅝, 2¾, and 3 inches. Each net was 510 feet long and 5 feet deep. In actual practice various lengths of each mesh were fished depending on the amount of serviceable gear on hand, but results for analysis have been adjusted to represent the catch of a standard gang. In the *Fulmar* operations in northern Lake Michigan during 1932, the largest (3-inch) and smallest (2⅜-inch) mesh sizes were not fished. In the *Cisco* studies, however, all meshes were fished at each station.

The combination of data from various depths, locations, and times of the year in this presentation disregards the known variations of size, abundance, and species composition with depth, location, and time. These combinations were made only after examination of detailed data revealed that no erroneous general conclusions would result. In all situations the changes from 1930-1932 to 1954-1955 were so large as to be clearly evident despite the combination.

Abundance of Chubs

The abundance (number of fish per standard gang) of *hoyi* (the smallest chub) increased greatly between 1932 and 1954 (Table 1), before and after the sea lamprey became established.[1] Among the larger species, *artedi* remained the same or increased slightly in all areas and *kiyi* remained the same off the east shore of southern Lake Michigan, but in all other areas chubs, except *hoyi,* were far less plentiful in the later period. In fact, the two largest species *(johannae and nigripinnis)* were absent from the 1954-1955 catches. A few *nigripinnis* (17 fish) were taken in nylon nets that were fished to obtain biological and distributional data on the chubs but no *johannae* were taken during the entire study even though nets were specifically set in areas where they previously had been abundant. The last positive record of *johannae* in Lake Michigan was made in June 1951 when Stanford H. Smith identified several specimens in the catch of commercial nets set at 100 fathoms in Grand Traverse Bay.

The abundance figures (Table 1) clearly demonstrate that the expected results of the addition of the sea lamprey to the deep-water food chain (Fig. 4) actually have come about. The smallest chub *(hoyi),* relieved of predation and strong competition for food, has increased greatly in numbers. The previously abundant medium-sized chubs *(alpenae, kiyi, reighardi,* and *zenithicus)* have decreased sharply, and the largest species *(johannae* and *nigripinnis)* have suffered the same fate as the large lake trout and burbot—near-extinction. *Artedi* which occurs in abundance in shallow areas of the lake is almost free of lamprey predation and has

[1]Summary tables of abundance and length composition of chubs in 1930-1932 were supplied by Dr. John Van Oosten, U. S. Fish and Wildlife Service who directed the operations of the *Fulmar.*

TABLE 1.—*Number of chubs taken in Lake Michigan from gill nets of identical specifications fished at the same depths, locations, and time of the year in 1930-1932 and 1954-1955.*

[Expressed as catch per 1,530-foot gang with equal amounts of 2½-, 2⅝-, and 2¾-inch mesh in the north end and as catch per 2,550-foot gang with equal amounts of 2⅜-, 2½-, 2⅝-, 2¾-, and 3-inch mesh in south end]

Species	North end[1]		South end			
			West shore[2]		East shore[3]	
	1932	1955	1930-1931	1954-1955	1930-1931	1954-1955
L. alpenae	24.3	0.8	12.5	6.5	65.3	24.6
L. artedi	0.6	0.7	0.8	1.9	2.5	2.9
L. hoyi	26.8	54.4	49.0	122.7	138.7	495.5
L. johannae	0.4	0	2.3	0	13.1	0
L. kiyi	6.6	3.8	39.8	7.6	41.2	44.3
L. nigripinnis	0.3	0	1.2	0	2.7	0
L. reighardi	12.0	6.5	24.4	6.9	136.8	18.2
L. zenithicus	9.7	1.0	14.1	12.7	20.5	12.1
Unidentified	4.2	0.2	12.9	3.1	17.1	8.3
Total	84.9	67.4	157.0	161.4	437.9	605.9
Number of gangs	58	20	26	18.5	32	30
Average nights fished	6.2	3.7	12.4	4.0	10.6	4.0

[1]Nets set at 50 fathoms off Manistique and Charlevoix and southwest of Beaver Island.

[2]Nets set at 30 and 70 fathoms in the vicinity of Manitowoc and at 25 and 50 fathoms near Racine.

[3]Nets set at 25 and 60 fathoms in the vicinity of Ludington and at 25 and 50 fathoms off Grand Haven.

been more than able to maintain its small numbers in the deep-water community.

Although the species composition of chubs has been modified greatly, the total abundance has not undergone a drastic change (Table 1; Fig. 6). Furthermore, the greater abundance of chubs on the east than on the west shore of central and southern Lake Michigan that existed in 1930-1932 (see Van Oosten, 1933, and papers by Jobes) was still evident in 1954-1955. Thus whatever factor or factors that regulate the availability of fish on the two shores have not been changed by modification of the fish populations.

The change in abundance of *hoyi* in 1954-1955 varied greatly in different sections and depths of the lake (Table 2). Only at Charlevoix was *hoyi* less abundant (index value, 88 percent) than it had been in 1932. Earlier studies showed that *hoyi* in the northern sections of the lake were 2.3 to 2.7 inches longer, on the average, than in other sections (Jobes, 1949b). Thus they would be more vulnerable to attack by the sea lamprey and capture by the commercial fishery. In other regions of Lake Michigan *hoyi* had increased to 111 to 1,136 percent of its 1930-1932 abundance. The average index value was 347 percent for all locations (Table 2). The percentages of the other species varied irregularly from area to area

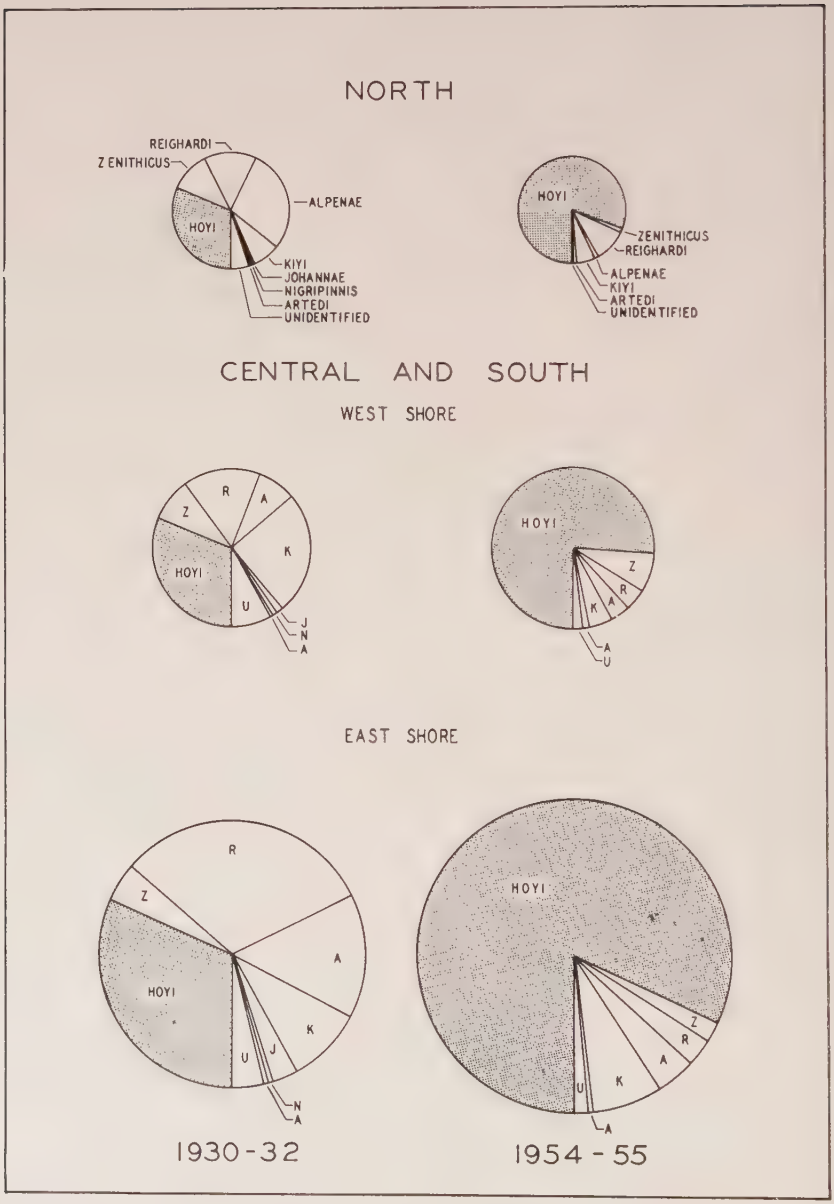

FIGURE 6.—Abundance and species composition of chubs in 1930-1932 and 1954-1955, in different areas of Lake Michigan. Area indicates relative abundance; see Table 1 for numerical values.

because small numbers of each were taken in many localities. Data for other species have, therefore, been combined (Table 2). In all locations the abundance of chubs other than *hoyi* has decreased. This segment of the population ranged from 13 to 73 percent of its 1930-1932 level and averaged 37 percent—a net decrease in abundance of 63 percent.

Length Composition of the Chub Population

A selective destruction of large chubs that was strong enough to change radically the species composition of the population should be expected also to modify the length composition of the stock. In fact, the greater abundance of the small, slowly growing *hoyi* has already dictated that such a change must occur.

Chubs are characteristically larger in the northern end of Lake Michigan than in the remainder of the lake and must, therefore, be treated separately

Table 2.—*Changes in availability of different segments of the chub population of Lake Michigan from 1930-1932 to 1950.*

[Numbers of chubs per gang of gill nets in 1954-1955, expressed as percentages of the catch in the same gear in 1930-1932. Number of fish per standard gang 1930-1932 and 1954-1955 respectively in parentheses.]

Location	Depth (fathoms)	1954-1955 catch as percentage of 1930-1932 catch	
		Leucichthys hoyi	Other species[1]
North			
Manistique	50	420 (14.7-61.7)	23 (55.9-13.1)
Island area	50	236 (29.7-70.1)	30 (62.3-18.6)
Charlevoix	50	83 (36.0-31.5)	13 (56.2-7.2)
Central			
Manitowoc	30	111 (69.8-77.8)	55 (47.8-26.2)
Manitowoc	70	389 (8.7-33.8)	15 (188.6-28.9)
Ludington	25	331 (111.5-369.6)	14 (270.0-37.5)
Ludington	60	1,136 (58.2-661.3)	73 (162.8-119.4)
South			
Racine	25	299 (70.1-209.3)	32 (103.4-32.7)
Racine	50	357 (47.3-169.0)	73 (92.4-67.7)
Grand Haven	25	286 (262.6-751.9)	28 (500.2-138.0)
Grand Haven	50	163 (122.3-199.4)	56 (263.8-146.5)
Average		347	37

[1]Includes unidentified chubs.

in considerations of length composition. In fact, chubs in the north averaged 1.3 inches longer than in central and southern Lake Michigan in 1930-1932 (Table 3). This difference was reduced to 0.6 inch in 1954-1955, due to the greater selective destruction of large fish in the north, where more large fish occurred.

Changes of length were large in each area. Chubs that averaged 11.4 inches in the northern portion of the lake in 1932 were only 9.2 inches in 1955—a decrease of 2.2 inches. In the central and southern portion the chubs averaged 10.1 inches in 1930-1931 and 8.6 inches in 1954-1955, a decrease of 1.5 inches. The change in the lengths of the chub catch is shown more clearly by the length-frequency distribution (Table 3, Fig. 7). The shorter groups that were sparsely represented in the catch during the early 1930's have become the dominant length groups in the recent catches. The shift to shorter length is not entirely due to the greater abundance of the small *hoyi* and lesser abundance of larger species. Pre-

TABLE 3.—*Length distribution of chubs of different sections of Lake Michigan in 1930-1932 and 1954-1955.*

[Fish were taken in experimental gill nets of identical specifications fished at the same depths, locations, and times of the year in 1930-1932 and 1954-1955. Frequencies are expressed as percentage of fish in each length group. Fish from 2½, 2⅝-, and 2¾-inch mesh combined]

Total length (inches)	North		Central and South	
	1932	1955	1930-1931	1954-1955
5.5- 5.9	>0.1	..	..	0.3
6.0- 6.4	..	..	0.4	1.0
6.5- 6.9	..	0.4	1.8	4.2
7.0- 7.4	>0.1	1.3	6.9	14.1
7.5- 7.9	0.4	8.3	7.0	17.5
8.0- 8.4	1.0	15.3	4.6	12.9
8.5- 8.9	1.2	17.2	4.3	11.4
9.0- 9.4	1.7	15.1	4.4	9.6
9.5- 9.9	2.5	15.1	6.5	9.8
10.0-10.4	9.0	16.2	14.5	8.5
10.5-10.9	21.4	7.4	17.3	6.1
11.0-11.4	20.2	2.8	15.1	2.8
11.5-11.9	14.1	0.9	9.0	1.1
12.0-12.4	10.3	0.2	5.1	0.4
12.5-12.9	8.5	0.1	1.6	0.2
13.0-13.4	4.4	..	0.5	0.1
13.5-13.9	2.4	..	0.4	..
14.0-14.4	1.3	..	0.2	..
14.5-14.9	0.6	..	0.1	..
15.0-15.4	0.3	..	>0.1	..
15.5-15.9	0.3	..	0.1	..
16.0-16.4	0.2	..	..	..
16.5-16.9	≥0.1	..	0.1	..
17.0-17.4	0.1	..	>0.1	..
18.5-18.9	>0.1	..	..	..
Average length	11.4	9.2	10.1	8.6

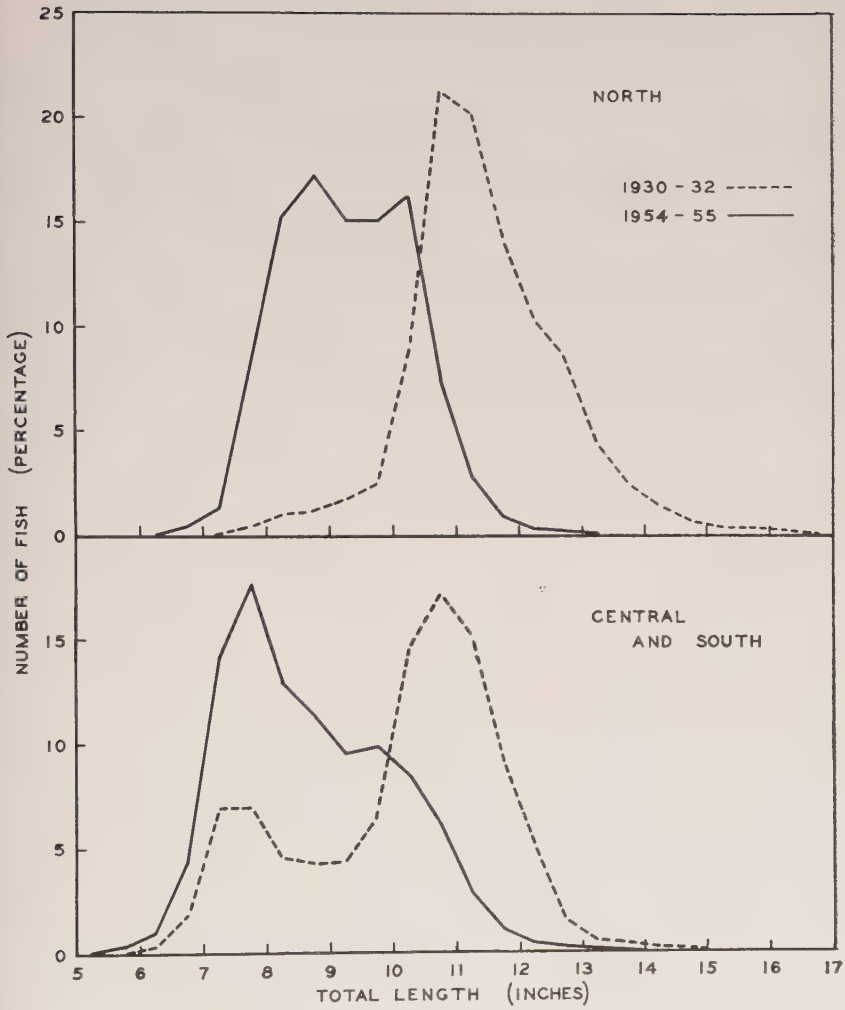

FIGURE 7.—Length distribution of chubs of Lake Michigan caught in identical gear before and after the sea lamprey became established.

liminary examination of the length distribution of the individual species shows a pronounced decline in length for each.

Effect of Changes in the Chub Population on the Commercial Fishery

An historical review of the chub fishery clearly indicates a long-term reduction in the size of fish in the chub population in Lake Michigan (Hile and Buettner, 1955). The two largest species, *johannae* and *nigripinnis*, almost extinct now, were major contributors to the chub catch prior to the turn of the century but were only lightly represented in 1930-1932 (Table 1.) At this same period the medium-sized species *(alpenae, kiyi, reighardi, zenithicus)* were abundant and in high demand. Although its larger individuals have contributed significantly to the catch, *hoyi* has always been considered a nuisance by the commercial fishermen who have avoided it wherever possible by not fishing in areas where it is abundant, and by hanging their gill nets "tight" so that bloaters (all small chubs but mostly *hoyi)* are less likely to be caught.

In recent years when the chub fishery of Lake Michigan has reached its greatest intensity (Hile and Buettner, 1955), *hoyi* is the only generally abundant species. The abundance of medium-sized fish is variable in local areas. Thus, for some fishermen the recent conditions have not been as

Table 4.—*Percentage of chubs shorter than 10 inches and 10 inches and longer taken from Lake Michigan in experimental gill nets of identical specifications in 1930-1932 and 1954-1955.*

[Figures represent all fish taken from a gill net with equal amounts of 2½-, 2⅝-, and 2¾-inch mesh]

Location	Depth (fathoms)	Percentage of chubs			
		Shorter than 10 inches		10 inches and longer	
		1930-1932	1954-1955	1930-1932	1954-1955
North					
Manistique	50	8.6	79.2	91.4	20.8
Island area	50	4.3	65.1	95.7	34.9
Charlevoix	50	7.7	73.0	92.3	27.0
Central					
Manitowoc	30	56.3	70.8	43.7	29.2
Manitowoc	70	27.6	73.7	72.4	26.3
Ludington	25	39.7	83.6	60.3	16.4
Ludington	60	34.3	82.7	65.7	17.3
South					
Racine	25	34.8	76.9	65.2	23.1
Racine	50	55.2	96.8	44.8	3.2
Grand Haven	25	21.1	85.8	78.9	14.2
Grand Haven	50	18.5	75.9	81.5	24.1
Average		28.0	78.5	72.0	21.5

acute as they have been for others. Still *hoyi* is more important in supporting the fishery in all areas than it has ever been. In many sections commercial fishermen are forced to fish for and market at low prices these small chubs that were previously discarded. Some fishermen, when faced with this prospect, have gone out of business.

Although *hoyi* is generally considered undesirable on the market because of the thinness of its meaty portions, size remains the primary criterion in determining the marketability of chubs. The size of each species has declined; thus, the size of individuals in, rather than the species composition of, the population determines the former and recent potential contribution to the commercial fishery. If it is assumed arbitrarily that chubs 10 inches and longer have consistent market demand, 72.0 percent of the chubs taken in mesh sizes most commonly used in the chub fishery (2½, 2⅝, and 2¾ inches) were marketable in 1930-1932 (Table 4). In 1954-1955, however, only 21.5 percent of the chubs taken in nets of the same mesh sizes were marketable. The change was most pronounced in the northern portion of the lake where previously over 90 percent of the chubs exceeded a length of 10 inches and more recently 34.9 to 20.8 percent were marketable. Hardest hit, however, are some areas in the southern portion of the lake where as little as 14.2 to 3.2 percent of the recent catch has been of marketable size.

Data from the 1930-1932 study show that the average length of *hoyi* taken in gill nets increases as the mesh size decreases (Jobes, 1949b). This

TABLE 5.—*Average length of chubs taken in Lake Michigan in experimental gill nets of identical specifications in 1930-1932 and 1954-1955.*

Location	Depth (fathoms)	Average total length (inches) of chubs caught in			
		2⅜-inch mesh		2½-, 2⅝-, 2¾-inch mesh	
		1930-1931	1954-1955	1930-1932	1954-1955
North					
Manistique	50	..	9.5	11.2	9.1
Island area	50	..	9.7	11.6	9.4
Charlevoix	50	..	9.8	11.4	9.2
Central					
Manitowoc	30	10.1	9.6	9.4	9.0
Manitowoc	70	10.1	9.7	10.3	9.0
Ludington	25	10.2	9.5	9.9	8.6
Ludington	60	10.1	9.3	10.1	8.9
South					
Racine	25	10.3	9.3	10.0	8.8
Racine	50	..	..	9.5	7.6
Grand Haven	25	10.4	9.4	10.5	8.5
Grand Haven	50	10.1	9.2	10.7	8.7
Average					
All data		10.2	9.5	10.4	8.8
Central and south		10.2	9.4	10.1	8.6

peculiar relation holds true because the smallest mesh size used in these studies (2⅜ inches) approaches the size at which *hoyi* is most effectively gilled. Most *hoyi* pass through larger mesh sizes; therefore, as the mesh size increases a higher percentage of these fish are caught by entangling their loose and rather extended mouth parts in the net. In a population dominated by *hoyi* it should be expected that a smaller mesh size should produce a larger fish. Even in 1930-1932, when *hoyi* was abundant but did not dominate the population, the average size of chubs taken in commercial meshes (2½ to 2¾ inches) in the southern section of the lake (where all meshes were fished in both periods) was 0.1 inch smaller than those taken in the 2⅜-inch mesh (Table 5). The greater difference of 0.8 inch occurred in the same area of the lake, however, when *hoyi* dominated the population in 1954-1955. Thus if the chub fishery should at some time become predominately dependent on *hoyi* for support, a mesh size smaller than the current 2½-inch minimum should be considered.

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LIMNOLOGICAL SURVEYS OF THE GREAT LAKES—EARLY AND RECENT

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ABSTRACT

Early explorations on the Great Lakes were concerned largely with things easily collected or observed—common organisms, water levels, surface temperatures . . . Even when more scientific studies were undertaken, they were at first scattered and small-scale. Effective surveys became possible only through inter-agency cooperation which permits a pooling of facilities, staff, and equipment. Expansion of limnological research on the Great Lakes has been rapid in later years and the outlook for the future is good.

The Great Lakes of east-central North America have practically been bypassed during the formative period of the relatively young science of limnology. It is not difficult to understand why this largest fresh-water lake system, with its major bodies ranging from the largest to the thirteenth-largest fresh-water lake in the world, has always been looked upon with great interest. It is surprising, however, that these lakes, located in a rich and densely populated section of the earth, have been so little explored until recent years. Problems of obtaining staff, specialized equipment, and vessels for operating on the lakes long have impeded major investigations. In recent years, however, increased interest in fishery problems and the expanding use of the lakes as a source of water, and for navigation and waste disposal have created the economic pressure required to bring about more comprehensive studies than have previously been possible.

The large size of the Great Lakes has imposed new operational requirements in the field of limnology and has necessitated some modification of concepts which have been largely formulated from studies of smaller bodies of water. Ideas have been borrowed from the oceanographer along with equipment with which to explore them. Because of their confined nature as compared with the oceans, many oceanographic concepts are not fully applicable, and new hypotheses have to be developed to interpret and describe properly the limnological features of these large inland lakes. This situation in turn may stimulate new ideas in the field of limnology as a whole, for what happens in the Great Lakes on a conspicously large scale may also be occurring in smaller bodies of water in proportion.

Early Explorations

The early scientific studies of the Great Lakes gained momentum in the first quarter of the nineteenth century (see Leverett and Taylor, 1915) when geologists and cartographers started compiling information on the size, configuration, and geological structure of the lake basins. These basic records on the morphometry of the lake basins provided a useful background for the early limnological observations.

Although their curiosity ran high, early investigators of the Great Lakes were limited in their facilities, equipment, and techniques and studied only things that were easy and simple to measure or collect. Water-level fluctuations attracted much early attention (Bigsby, 1829; Sharpe, 1831) because changes were often great and sometimes very rapid. Earliest observations of unusual water-level fluctuations were passed on as stories by early settlers and were eventually recorded in early reviews (Whittlesey, 1875). A number of these observations were probably based upon "tidal waves" such as the one that occurred in Lake Michigan in 1954 (Ewing, Press, and Donn, 1954). The recognition of the regularity of water-level fluctuations stimulated studies to determine the periodicity and resolve the question of lunar influence (Ruggles, 1843; Whittlesey, 1859). These inquiries demonstrated that the regular periodicity of prominent fluctuations could not be related to influences of the moon. It was concluded that the "tides" may result from planetary influences, modified or at times dominated by winds. A long-term study in Lake Michigan (Graham, 1861) clearly demonstrated a lunar tide of 0.15 to 0.20 foot which is generally overshadowed and hidden by seiche action. The long-term seasonal and annual changes in water level also drew the attention of early investigators (Dewey, 1859; Whittlesey, 1860) who started a series of records that have provided a base for better understanding and even predicting seasonal and annual lake levels.[1]

Water temperature was easy to obtain, and it received some early attention (Dewey, 1838, 1839). Temperature was not given any appreciable study, however, until after the Negretti-Zamba type of reversing thermometer was put into use during the last quarter of the nineteenth century (Drummond, 1890; Coleman, 1922). Records of subsurface temperatures that were possible with the reversing thermometer opened an entirely new field of speculation as to the circulation and thermal structure of the lakes. Of particular interest were records of summer temperature in deeper sections of the lakes where the water was less than 4°C. This phenomenon was at first puzzling but later it was adequately explained as an effect of pressure on the temperature of maximum density of water (Wright, 1931). Although temperature differences between the surface and bottom were great enough for the formation of a thermocline, few vertical records

[1] Monthly lake-level reports and news releases issued by the Lake Survey, U.S. Army Corps of Engineers, Detroit, Michigan.

were satisfactory enough to detect it. Records available up to the early 1930's led to the impression that: ". . . regional thermoclines occur at certain times and places, in the other [than Lake Erie] Great Lakes," and ". . . in such waters there is no continuous thermocline extending from one shore to the other, as is the case in the inland lakes . . ." (Welch 1935, p. 56). With the advent of the bathythermograph in the early 1940's which provides a complete thermal record form surface to bottom it was discovered that themoclines are a regular feature of the deeper areas of the Great Lakes (Church, 1942, 1945; Hachey, 1952; U. S. Fish and Wildlife Service records, unpublished).

The collection of biological information on the Great Lakes was probably hampered by difficulties of getting suitable boats for making observations and obtaining samples. Some of the earliest records of invertebrate life in the Great Lakes (about 1870) were based on the contents of "whitefish" (probably *Leucichthys* spp.) stomachs (Hoy, 1872). Dredging studies initiated during this period (Smith, 1871, 1874; Stimpson, 1871) gave a more adequate picture of deep-water life and provided information on bottom materials at various depths. Difficulty in obtaining a means of getting onto the lake also limited plankton collections which were often restricted to inshore areas (Forbes, 1891).

Earlier Limnological Surveys

Perhaps the earliest organized survey party to record general limnological information on the Great Lakes was the group headed by Louis Agassiz on Lake Superior in 1848. This party of naturalists and students traveled by canoe from Sault Ste. Marie, Michigan, to Fort William, Ontario, collecting and observing whatever they could. The narrative of the trip recorded by J. Elliot Cabot (Agassiz, 1850) includes a number of general remarks on the relative temperature, color, and transparency of the water, and on water-level fluctuations. The party measured transparency by lowering a tin cup which was seen to a depth of 42 feet. This group made no great contribution to our knowledge of Great Lakes limnology but their effort did represent a start in organized surveys of the lakes.

The increased use of the Great Lakes for navigation, as a source of drinking water, and the conflicting use as a depository for domestic and industrial wastes created a need for more knowledge of water movements (Clark, 1892). To satisfy this need the U. S. Weather Bureau and the Meteorological Service of Canada released nearly 5,000 drift bottles throughout the Great Lakes over a 3-year period (1892-1894). Data from 672 bottles that were recovered were used by Harrington (1895) to establish his classical surface-current charts of the Great Lakes. These charts are open to serious criticism both in the manner in which they were compiled and in the light of subsequent information. Although Harrington mentioned the varying nature of water movements and the complex

of factors other than currents that may influence the movement of a drift bottle, the evidence suggests that in preparing his charts he relied more on general assumptions as to factors creating water movement than on his relatively scanty returns. These assumptions were that water tends to flow toward the outlet of a lake, that prevailing westerly winds create primary currents moving from west to east, and that when water moves in the direction of an inadequate outlet (or none at all) it must return in another current in an opposite direction. Harrington was influenced further by a firm belief that primary currents are persistent in direction but varied in velocity, and that secondary currents vary little in direction but greatly in velocity.

Even before Harrington's study, Clark (1892), from observations on Lake Ontario, concluded, "With the opinion that there are any regular, constant, well-defined lake currents, I feel inclined to disagree." In summarizing results of returns of drift bottles from Lake Erie in the early 1930's Wright (1955) observed: "Thus, while Harrington's data suggest great constancy in direction of currents, the data of this study emphasize their inconsistencies . . ." Highly variable water movements in Saginaw Bay also were demonstrated by the charts of the Michigan Stream Control Commission (Adams, 1937).

The strongest evidence of irregularity in currents of the Great Lakes, including on occasion circulation patterns directly opposite to those shown by Harrington's charts, has come from a study of Great Lakes Fishery Investigations, U. S. Fish and Wildlife Service, in Lake Michigan in 1954 and 1955. In this operation 6,300 drift bottles and other drift missiles were released at 5-mile intervals (usually 20 released at one location) over several east-west transects at 3- to 6-week intervals from April through November. Although analysis of the data is not yet complete, it has been demonstrated clearly that the major surface-current structure of Lake Michigan can change greatly over a 3-week period. These analyses are based on a better than 60-percent recovery. Sometimes recoveries from releases of one day along a single transect nearly equal the number that Harrington had for his entire study. Although some general tendencies in direction are apparent, the concept of a high degree of stability in surface-water movements of the Great Lakes, as implied by Harrington's discussion and charts, is not supported.

Jacob Reighard might be considered the originator of organized limnological research on the Great Lakes. He pointed out that individual investigators working separately and with limited facilities accomplish little more than the solution of small local problems (Reighard, 1894). Recognizing that little was known about the Great Lakes, Reighard (1899) called for general basic research that would produce in advance information that could be used to solve problems as they arise. Acting on these views, he organized the first cooperative research project on the Great Lakes. He established a laboratory on Lake St. Clair in the summer of 1893

under sponsorship of the Michigan Fish Commission in space supplied by a local citizen and with laboratory apparatus loaned by the University of Michigan. Reighard and five other investigators of various specialties in aquatic biology, who worked without compensation, joined their efforts to study the lake and its biota. In 1894 H. B. Ward (Ward, 1896), in Reighard's absence, headed a similar cooperative group under the same sponsorship that studied the Little Traverse Bay region of Lake Michigan. Although both survey groups were limited to small boats and the occasional use of steam tugs in collecting trips, they made notable contributions to knowledge of conditions in the lakes and their flora and fauna. Reighard's surmounting limitations of expense, personnel, and equipment through the organization of cooperative investigational unit initiated a procedure that has since been a means of carrying out projects larger than would be possible for a single organization. It thus heralded a new and more productive era of limnological research on the Great Lakes.

The drastic changes in fish populations and the conspicuous insurge of domestic and industrial wastes into Lake Erie aroused much public concern in the early 1920's. This interest led to a series of investigations which together constituted a survey of Lake Erie (Wright, 1955) more comprehensive than any conducted on the other lakes. The Ohio Division of Fish and Game (later the Ohio Division of Conservation) started a program in 1926 to study aquatic conditions in western Lake Erie. This study was enlarged through the cooperation of the U. S. Bureau of Fisheries in 1929 and 1930.

An intensive limnological survey of the eastern end of Lake Erie was conducted in 1928 by the State of New York (Fish, 1929; Moore, 1929) through the cooperative efforts of the New York Conservation Department, the U. S. Bureau of Fisheries, the Province of Ontario, the City of Buffalo, and the Buffalo Museum of Science.

Although the two groups of cooperating agencies worked independently in the west and east ends of the lake, their combined studies represent a comprehensive hydrographic and biological survey of Lake Erie. A most notable advance of these surveys was the initial use on the Great Lakes of vessels especially equipped for hydrographic studies.

Another major cooperative venture was started on Lake Michigan in 1930 through the joint efforts of the U. S. Bureau of Fisheries, the states of Michigan and Wisconsin, and four fish-net manufacturers. Although the survey was concerned primarily with problems related to the fisheries for lake trout *(Salvelinus namaycush), and chubs (Leucichthys* spp.), extensive limnological data were collected (Ahlstrom, 1936; Deason, 1932, 1936; Eggleton, 1936, 1937; Wright, 1931). Some of the records even now remain to be analyzed.

Our understanding of the thermal structure of the Great Lakes was advanced greatly by the development of the bathythermograph. Church (1942, 1945) was the first to use this instrument extensively in the Great

Lakes. His temperature survey of Lake Michigan in which he drew upon the assistance of lake ferries and the U. S. Coast Guard vessels gave the first positive evidence of the complexity of the temperature conditions in deeper waters of the lakes.

Although not a survey-type program, the work conducted through the years 1896-1955 at the Franz Theodore Stone Laboratory (Langlois, 1949), considered as a whole, has been an outstanding contribution to our knowledge of the limnology of western Lake Erie. Many researches have covered thoroughly various features of this area. Somewhat similar have been the long-term contributions of the Great Lakes Fishery Investigations of the U. S. Fish and Wildlife Service (Bureau of Fisheries prior to 1940). This group has compiled many observations of limnological conditions on the lakes which individually may be small but collectively constitute a broad background of material. A series of studies conducted from 1911 to 1914 at the Great Lakes station of the Biological Board of Canada developed extensive information on the fauna, flora, and hydrographic conditions of Georgian Bay, Lake Huron (Prince, 1915). These along with many other individual efforts such as Daily (1938); Eddy (1943); and Gottschall and Jennings (1933); have done much to add to our knowledge of the Great Lakes.

Recent and Current Limnological Research

Although a list of individual researches and surveys on the Great Lakes would be impressive, it does not reflect a correspondingly advanced state of understanding of the lakes. Studies have uncovered new questions more rapidly than they have answered old ones. Such a situation must, however, be healthy for it has fostered the creation of new organizations dedicated to Great Lakes research and has invigorated existing ones.

Most recently organized have been: the Great Lakes Commission, established in December 1955, an organization representing six Great Lakes states and dedicated to promote studies that will advance all uses of the Great Lakes; and the Great Lakes Fishery Commission, an international body established in October 1955, whose purpose, in addition to bringing about control of the sea lamprey, is to coordinate fishery and hydrographic research conducted by independent units and to support research activities of its own. Organizations that have been active in recent and current limnological research are mentioned in connection with the work in which they have been engaged.

During the last decade and particularly in the past 5 years Great Lakes research has been progressing at an increasing tempo. Early in this period the University of Western Ontario conducted a local but comprehensive limnological survey of western Lake Erie, the results of which are yet to be published. About the same time the Ohio Department of Natural Resources was increasing its research on the limnology of Lake Erie. The Ohio studies have led to a much better understanding of the general circulation (Verber,

1955), seiches, water temperatures, and climate of western Lake Erie, and some attention has been given to central and eastern parts of the lake. Other studies have dealt with the dispersion of industrial wastes in the lake (State of Ohio, 1953) and surveys of bottom materials, particularly in relation to sand deposits and shore erosion. Since 1953 the work of the Ohio Division of Shore Erosion on Lake Erie has been facilitated by a specially constructed and equipped hydrographic research vessel.

Possibilities for extensive long-term limnological research on the Great Lakes were increased when the U. S. Fish and Wildlife Service launched its research vessel *Cisco* in 1951 (Moffett, 1954). This boat is equipped with many of the latest devices for measuring, recording, sampling, and analyzing limnological features of the lakes. In 1951, the *Cisco* was used to map the bottom materials of Lake Michigan (Hough, 1952). This work led to a revision of the recent pleistocene chronology (Hough, 1955) by introducing the new low-water "Lake Chippewa" stage. In 1952 the vessel operated intensively in Green Bay and made brief exploratory runs into Lakes Huron, Michigan, and Superior; and in 1953 she was used in a general fishery and hydrographic survey of Lake Superior. Although much of the extensive limnological data collected in these years is still undergoing analysis, some data have found use in fishery studies (Eschmeyer, 1956; Smith, 1956). During 1954 a survey was conducted of the southern half of Lake Michigan and similar coverage was made on the northern half in 1955.

The "synoptic survey" was introduced to the Great Lakes in 1953 when the Ontario Department of Lands and Forests sponsored studies in which 5 and 6 boats operated simultaneously once a month during the summer to provide 1-day coverages of Georgian Bay. These surveys were so successful that they led to three synoptic coverages of Lake Huron in 1954 (Ayers, Anderson, Chandler, and Lauff, 1956) through the cooperative efforts of the Ontario Department of Lands and Forests, the University of Toronto, the Great Lakes Research Institute of the University of Michigan, the Michigan Department of Conservation, and the U. S. Fish and Wildlife Service. This type of operation was continued in 1955 when four synoptic coverages of Lake Michigan were made under the principal sponsorship of the Great Lakes Research Institute, and a survey of Lake Erie was made through the cooperative efforts of Ohio State University, the Ohio Department of Natural Resources, the New York Conservation Department, and the Ontario Department of Lands and Forests. Also in 1955, preliminary 1- and 2-vessel surveys were conducted on Lake Ontario by the Ontario Department of Lands and Forests. Thus, the cooperative research program visualized by Reighard is being realized fully some 60 years after he set up his first cooperative laboratory on Lake St. Clair in 1893. In 1956, however, only one cooperative synoptic survey was in progress—a coverage of Saginaw Bay sponsored jointly by the U. S. Fish and Wildlife Service and the Michigan Department of Conservation.

Limnological studies in 1956 are mostly independent ventures sponsored by a number of organizations. The Great Lakes Research Institute is conducting intensive studies of the Mackinac Straits area of Lakes Huron and Michigan. The South Baymouth Laboratory of the Ontario Department of Lands and Forests is continuing periodic measurements of the physical and chemical conditions in South Bay, Lake Huron. Studies of Lake Ontario are being conducted by the Ontario Department of Lands and Forests with a full-time hydrographic research vessel. The Ohio Division of Shore Erosion is continuing its broad studies of circulation patterns and water-level fluctuations in Lake Erie. The U. S. Fish and Wildlife Service, in addition to the cooperative synoptic surveys of Saginaw Bay, has assigned its research vessel *Cisco* to studies of Saginaw Bay, its adjacent waters, and southern Lake Huron.

The major barriers to limnological research of the Great Lakes have indeed been broken. The scale of field operations has reached an all-time high. The greatest amount of data ever compiled on the Great Lakes as a whole is undergoing analysis, and the talent of more investigators than ever before is being directed toward limnological research. Although the future is always uncertain, there is little doubt that the interest and activity in this field will continue to grow.

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CURRENT FISHERIES RESEARCH BY CANADIANS ON THE GREAT LAKES

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Abstract

The activities indicated are reviewed. They fall into two categories: 1. A contribution towards eliminating sea lamprey from the Great Lakes; 2. Some general fishery research.

The activities considered are those that until now have been sponsored by the Federal-Provincial Great Lakes Fisheries Research Committee, a group of eight, four representing the government of Canada and four the government of Ontario. It was formed in 1953 both to initiate immediate action to control sea lamprey and to intensify general research on the Canadian fisheries of the Great Lakes. Since these activities are included in the duties assigned to the recently formed Great Lakes Fishery Commission the Committee's program is now being absorbed into the more general program of the Commission.

The Committee was formed with the understanding that the Canadian government would finance most sea lamprey control activities while the Ontario government financed all biological reasearch that was not concerned with lampreys. Lamprey control measures were to be considered as experimental and initially to be concentrated on Lake Superior. The Committee named a sub-committee of two members, F. E. J. Fry and W. M. Sprules (who were designated as co-directors) to implement its program. The co-directors asked J. M. Speirs to act as secretary of their two-man sub-committee with responsibility for day-to-day supervision of the program. Later, I was asked to direct the Committee's program temporarily in addition to my normal duties, and took charge on April 1, 1955, with the title "Co-ordinator of Research."

Although control of the sea lamprey was not the most important problem, it was regarded as the most pressing one. The sea lamprey had already made it unprofitable to fish for lake trout in Lake Huron and in Lake Michigan and seemed likely soon to do the same in Lake Superior. The need to bring the lamprey under control as soon as possible seemed urgent enough that it was decided to begin immediately the use of a control technique developed by the U. S. Fish and Wildlife Service even though it would not necessarily be as effective under the different

conditions found in Ontario. The technique, which is described in published papers, consists of stopping lamprey from ascending their spawning streams. In most situations the movement of lampreys is blocked by placing electrodes in the water from bank to bank to produce an electrical field in the stream that immobilizes or kills lamprey. In a few streams it is practical to use mechanical barriers rather than electrical barriers.

In 1953 three barriers were built in Canada in the immediate neighborhood of Sault Ste. Marie and more were built in 1954, 1955, and 1956. By the end of 1956 every stream on the Canadian side of Lake Superior in which lamprey are likely to spawn will have a barrier—a total of approximately 40 structures.

Barriers are installed in those streams where sea lamprey are known to spawn or in streams where it seems likely that they will spawn as their numbers increase. In addition to streams with barriers, more than 100 Canadian tributaries to Lake Superior are kept under observation to see whether lamprey runs will develop in them. Whenever possible, several visits are made to these streams during each spawning season to see whether lamprey are spawning in them. On many of them,however, the spawning grounds are so difficult to reach that it is not practical to make these observations. "Check weirs" are installed near the mouths of such streams. These weirs are actually traps designed to catch and hold all lamprey that attempt to ascend the stream.

It soon became apparent that the type of electrical barrier developed in the United States was not altogether suitable for conditions on the north shore of Lake Superior. In many Canadian streams barriers of this type failed to produce an electrical field that always killed sea lamprey. It has since been found that barriers suitable for Michigan streams failed in Canadian streams because of a difference in electrical resistivity. In the streams on the south side of Lake Superior resistivity averages about 8,000 ohms per centimeter cube as compared with an average of 20,000 ohms in those on the north shore (range 4,200 to 40,600, most readings between 15,000 and 25,000). This difference is not surprising since resistivity is inversely related to the amount of material dissolved in the water and since the north shore streams generally drain extensive areas of relatively insolvable precambrian granite. Therefore electrode arrays which would produce a satisfactory electrical field in waters of relatively low resistivity proved inadequate in Canadian streams where resistivity was considerably higher.

To overcome this difficulty, two new arangements of electrodes were developed which would increase the current used by a given barrier and thereby increase its blocking effect to a satisfactory level. The arrangement most commonly used is called the modified ground electrode and is simply an elaboration of the ground electrode used in the United States. It differs by having four lengths of pipe parallel to one another instead of the single lengths of pipe found in the ordinary ground elec-

trode. This modified ground electrode is effective in water as much as 3 or 4 feet deep. For greater depths the "rack-type" electrode arrangement is used. This barrier has horizontal electrodes much closer together than was practical with the hanging electrodes used originally. The prototype of another type of electrical arrangement is being tested in which wooden pilings are driven into the bottom solidly enough to resist floods and ice, and each pile is sheeted with metal to make it into an electrode.

Another difficulty was probably also the result of differences between conditions on the two sides of the lake. Within the electrode array of the original barrier there was a trap designed to catch alive all migrating fish so that they could be released beyond it. None of these traps was effective under Canadian conditions; eventually the use of this type of trap was abandoned. Instead a modified pound net is now set below each barrier to intercept migrating fish before they reach the lethal electrical field. This arrangement proved to be so effective that the fish kill in 1956 was negligible compared with the kill in 1955.

The known kill of sea lamprey at Canadian barriers on Lake Superior was 2,131 in 1955 and will be about 2,400 in 1956. Probably many of the lamprey killed are carried away by the current, or are not seen because of muddy water. The number recovered is therefore presumed to be less than the number actually killed although there is no way of judging how much less. Flood conditions in 1956 made recovery of dead lamprey more difficult than in 1955, which suggests that the actual kill might have increased by considerably more than is indicated by the small increase in number recovered. Practically all of the lamprey recovered in 1956 were killed by barriers within 100 miles of Sault Ste. Marie even though devices were operated much further away. This may indicate that sea lamprey are well established only in the southeast corner of Lake Superior.

The first barriers to be put into operation were those on the few Canadian tributaries which have sizeable sea lamprey runs. Barriers have been operated on all such streams since the beginning of the 1955 season. Although the barriers have not been completely effective, observations on the spawning grounds above them have indicated little escapement. Therefore, it seems likely that very few sea lamprey have spawned in Canadian tributaries of Lake Superior since the spring of 1954. In other words the expected contribution of Canadian streams to those year classes of lamprey which normally would have been available to prey on the fish of Lake Superior in 1959 and 1960 has probably been greatly reduced.

The many difficulties encountered in trying to prevent sea lamprey from spawning have emphasized so strongly the need for more information about them that considerable effort has been put into research on the animal. A study is being made of the exact conditions needed for successful lamprey spawning; it has shown that they can spawn successfully in water where there is absolutely no current. A study of sea lamprey ammocoetes has shown that they move considerably and even migrate from one

tributary to another so that they may be found in streams where spawning is impossible. A team of divers has been studying sea lamprey by direct underwater observations; so far they have produced considerable evidence that few adults pass through the canal at Sault Ste. Marie during the summer . Lamprey physiology is being studied with particular emphasis on the effects of electrical fields on the animal. Financial support is being given to Kleerekoper of McMaster University for physiological work; he has discovered that sea lamprey produce spike potentials which recur at 0.4-second intervals and that the resulting electrical field is around the head and forward from it.

In addition to the foregoing which are financed by the Federal government, some lamprey control has been financed by the Provincial government. The most important have been a number of stream surveys to get the information necessary for determining where barriers are required. Another contribution has been the collection of information on the extent to which various species of fish are scarred by lamprey. This information is collected through questionnaires to the commercial fishermen and is periodically tabulated and made available to all concerned.

The main contribution of Ontario to the Committee's program has been in the form of financial support of fishery research. The biggest operation is at South Bay on Manitoulin Island, Lake Huron, where work recently done under the Committee has been simply a continuation of research started there almost a decade ago and which is well known through published papers. South Bay can be regarded as a microcosm where techniques for working on larger bodies of water can be developed. A good deal of information has been collected on the fish of South Bay and there seems to be a good chance that when it is analysed a formula will emerge which will show fish production in South Bay can be maximized. Since maximization of production is a major problem on all the Great Lakes this development within the South Bay microcosm promises to be of great general interest.

Considerable numbers of the lake trout × speckled trout hybrid known as "splake" have been planted in South Bay. The hybrid grows faster than either of the parents and appears to be much less susceptible to lamprey attack. None of the considerable numbers of marked lake trout recently planted in South Bay have managed to survive lamprey attacks long enough to reach maturity, but this is not true of the splake.

A start has been made on extending the studies at South Bay to Lake Huron as a whole. Personnel based at the South Bay Laboratory have also been studying Lake Superior fisheries. Of almost 6,000 Lake Superior trout tagged in 1954 and in 1955 enough were recovered by commercial fishermen to indicate an intensive fishery. The tagged trout travelled considerable distances and a few crossed the international boundary. Some records of Lake Superior commercial fishermen were also studied; they show that for several years catch per net has been declining.

In Lake Erie much information has been accumulated by examining the commercial catch; to date these data are not analysed. The Lake Erie group has also been cooperating with biologists in the United States, particularly those in Ohio, to tag Lake Erie fish as a means of studying their movements. This study is by no means complete but the data indicate that practically every species of commercial fish in Lake Erie moves extensively and that migration across the international boundary is common.

On Lake Ontario an experiment to determine the effectiveness of planting whitefish fry as a management technique has been going on for some time and is now almost completed. The experiment consists of using standard techniques for hatching and planting whitefish fry except that the fry are planted only in alternate years. The composition of fishermen's catches is studied in subsequent years to see whether the year classes which were reinforced by hatchery plantings are stronger than the year classes which were not so reinforced. The data so far collected tend to show that plantings do not influence year-class strength appreciably.

The group on Lake Ontario is also cooperating with New York State investigators in an experiment to determine whether the planting of lake trout fingerlings is likely to be an effective way to rehabiltate the trout populations of the lake. The experiment is incomplete but examination of small lake trout (below legal size) indicates that the planted fish (which were marked) are contributing significantly to the oncoming year classes.

Provincial investigators have been collecting limnological data on the Great Lakes and have had an informal working arrangement with United States scientists for taking simultaneous limnological observations. Particular emphasis has been put on Lake Huron but considerable work has been done on Lake Erie and some on Lake Ontario. A report on the 1954 Lake Huron surveys will be published shortly.

THE ROLE OF THE GREAT LAKES FISHERY COMMISSION IN THE SOLUTION OF GREAT LAKES PROBLEMS

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ABSTRACT

The Great Lakes Fishery Commission was established by treaty between the United States and Canada. Under the terms of the Convention the Commission is charged with the implementation of a program for the control of the sea lamprey and with the coordination of fishery research by various agencies. In the performance of its duties with respect to sea lamprey the Commission has contracted the operational phase of the program to the Fish and Wildlife Service in the United States and to the Fisheries Research Board in Canada. The Commission does not plan to engage in research but has the authority to do so should circumstances require.

Primary responsibility for preparing and recommending to the Commission the programs for sea lamprey control and fishery research lies with the five-man Scientific Advisory Committee, headed by the Executive Secretary of the Commission and having two members each from the United States and Canada. This Committee is aided by consultants from all regions of the Great Lakes. Further advice will be given to the United States and Canadian Sections of the Commission by lake Advisory Committees.

Present organizational arrangements must be viewed as tentative and subject to modification in the light of continuing experience.

In a broad sense the four papers just presented have outlined some of the major fishery problems in the Great Lakes. They have given us a picture of the research work which has been done and that which is now in progress. They have also indicated the great amount of research which must be undertaken in the future if these problems are to be solved. With this information in mind, I shall attempt to outline briefly the role which the newly formed Great Lakes Fishery Commission will play in the solution of these problems.

To do this most effectively, I should perhaps turn to the Convention which established this Commission and read to you from the pertinent articles. The Convention provides in Article IV:

> The Commission shall have the following duties:
>
> (a) to formulate a research program or programs designed to determine the need for measures to make possible the maximum sustained productivity of any stock of fish in the Convention Area which, in the opinion of the Commission, is of common concern to the fisheries of the United States of America and Canada and to determine what measures are best adapted for such purpose;

(b) to coordinate research made pursuant to such programs and, if necessary, to undertake such research itself;
(c) to recommend appropriate measures to the Contracting Parties on the basis of the findings of such research programs;
(d) to formulate and implement a comprehensive program for the purpose of eradicating or minimizing the sea lamprey populations in the Convention Area; and
(e) to publish or authorize the publication of scientific and other information obtained by the Commission in the performance of its duties.

Article V authorizes the Commission to conduct investigations, to take measures and install devices in the Convention Area and its tributaries for lamprey control, and to hold public hearings. Article VI requires the Commission to make use of official agencies of the Contracting Parties to the extent feasible, and authorizes it to make use of private or other public organizations or any person. The Convention is precise in its statement of duties. The Commission is to concern itself with three things: general fishery research; lamprey control; and the dissemination of information. It is to make maximum use of existing agencies.

Leaving aside for the present the matter of dissemination of information, let us examine more closely the Commission's duties with regard to general fishery research and lamprey control. You will note that the Commission is directed both to formulate *and implement* a comprehensive program for controlling lampreys. However, with regard to general fishery research, it is to "formulate a research program or programs"; it is to "coordinate research made pursuant to such programs and, if necessary, to undertake such research itself," and finally it is to "recommend appropriate measures."

This language requires a different approach to the discharge of these major duties. In the field of lamprey control, we are to develop and carry out a program. The Governments have placed ultimate responsibility for completion of the program in the Commission and have provided means for it to obtain the needed funds. The pattern is different with regard to general fishery research. Although the Commission is directed to formulate a research program, it is empowered only to coordinate research made pursuant to such a program. The two Governments did not intend that, as a general rule, the Commission engage in major research activities on its own, nor did they intend that the Commission direct the research activities of existing agencies in the two countries. It is to formulate a program, looking to existing agencies to carry it out, and it is to coordinate the work of these agencies. Finally, it is to recommend management procedures to the two Governments.

This distinction between operating patterns appears to be entirely reasonable. A lamprey control program requires a high degree of centralization in order to insure continuity and uniformity in the quality of work. To be successful, the program must insure the eradication of practically all the lampreys. A concerted, centrally directed effort is thus required.

The research problem is somewhat different. Fishery research in the Great Lakes is not new. Scientists of both countries have been working

in the Lakes for many years. It is true that they have had to work on a scale which is small in relation to the size of the problems which have faced them, but they have learned a great deal about the fishes and fisheries of the Lakes. The problems are more difficult than most—a fact which is not generally appreciated. Each lake has peculiarities which require that it be studied separately. On the other hand, the lakes have similarities which bind them together. Most of the fish are shore-dwelling species. That is to say, their habits relate to the shore even though the fish go out into deep water. The research problems in the lakes are something like coastal problems in marine fisheries, only they are much larger problems than those on any of our marine coasts, for there are some 8,300 miles of coastline.

A new research organization with a large staff of its own does not appear necessary to attack Great Lakes fishery problems. What is needed is a means of placing greater emphasis upon the problems. What is needed is a means of bringing the scientists and administrators of the several existing organizations together formally in order to turn the minds and knowledge of these people to a truly joint approach to Great Lakes fishery research; to have them develop a comprehensive program which promises solution to these problems; to have them agree among themselves on the role which each agency can best play in implementing such a program; and to encourage them to increase their efforts to the maximum. Once a program is in operation, a joint review of progress will be needed, modifications and shifts in emphasis must be made as required by newly discovered facts, and finally, the findings must be reviewed and recommendations made to the two Governments.

To recapitulate, in the field of lamprey control, the Commission will plan and carry out a control program; in general research, the Commission will work more as a means of focusing the attention of the various research agencies on area-wide problems.

You will understand that the Commission is empowered to undertake research on its own if necessary. It does not appear to us now that such activity will be required. However, should we find that existing agencies are unable to conduct certain studies which we believe to be necessary, we would undertake these studies as a Commission, either with a staff of our own, or on a contractual basis.

With these two different functions in mind, let us now look at the mechanics. The Commission is new, of course, and our thinking is still incomplete on some phases of our work. We have, however, decided to employ a small staff headed by an Executive Secretary. We have also decided to locate the staff in Ann Arbor, Michigan, a city centrally located and a center of fresh-water fishery research. Until a permanent appointment is made, Dr. James W. Moffett is filling the position of Executive Secretary, on loan from the Fish and Wildlife Service. We have also appointed a Scientific Advisory Committee to provide us with expert

advice. In view of the fact that a large committee would be cumbersome and difficult to convene, we have decided to limit it to two members from Canada and two from the United States. It is, however, empowered to have such advisors as it may desire. The Executive Secretary is Chairman of this Committee. Its other members are Dr. W. A. Kennedy of the Fisheries Research Board of Canada, Mr. Norman Baldwin of the Ontario Department of Lands and Forest, Dr. Moffett, and Dr. Charles Dambach of the Institute of Natural Resources, Ohio State University.

This Committee is, in our opinion, a most critical part of the organization. With its advisors, it will be a scientific body representing all areas, familiar with the views, capabilities, and problems of the Federal, State, and Provincial agencies, able to discuss problems, sift information, and present sound recommendations to the Commission. It will, we hope, be instrumental in the coordination of research.

We look to the Scientific Advisory Committee to draft for our approval a comprehensive lamprey control program. When we have approved a program, we shall then turn to the two Governments for funds to carry it out. We do not intend to employ a large staff for these operations. We consider ourselves fortunate to be able to contract with the Fish and Wildlife Service and the Fisheries Research Board to do the work for us. The Executive Secretary will maintain close liaison with these agencies to insure that the work is being carried out as specified, and the Scientific Advisory Committee will review developments and recommend modifications and additional work to the Commission.

As another means of achieving a high degree of coordination, the two Sections of the Commission are authorized to appoint advisory committees. These groups, appointed in accordance with United States and Canadian law and policy, will provide additional forums for stimulating interest and cooperation, for discussing needs and capabilities. We believe these national advisory committees will contribute greatly to the development and coordination of a sound program.

I would emphasize that these arrangements are not permanent. We must learn as we go along and change our organization as situations require.

I have attempted to give you a picture of the duties which the Convention has placed upon the Great Lakes Commission, and the way in which the Commission proposes to discharge these duties. Permit me to spend the remaining moments of the time allotted to me in a discussion of the programs which we have developed to date.

Because of the urgency of the problem and budget requirements, the Commission has found it necessary to move rapidly in the adoption of lamprey control programs for the fiscal year ending on June 30, 1957. We were not able to wait for the formation of the Scientific Advisory Committee or for consultation with agencies other than the Fish and Wildlife Service and the Fisheries Research Board. At our first meeting in Ottawa in April 1956, we adopted a program for the fiscal year ending

June 30, 1957. The program is essentially that proposed by the two Federal research agencies. It contemplates completion of the network of electromechanical barriers on streams tributary to Lake Superior, the installation of 55 barriers on Lake Michigan, the initiation of extensive surveys of the streams tributary to the North Channel, Lake Huron, and continued work on the testing of selective toxicants for use on lamprey larvae. The program, which has been approved by the two Governments, is expected to cost in the neighborhood of one million dollars. We have entered into a contract with the Fish and Wildlife Service for work in the United States. The Fishery Research Board is carrying out the program in Canada. The work is under way, and progress reports which we received at our meeting on July 30 and 31 were gratifying.

We have also been obliged to work out a lamprey control program for the next fiscal year, that ending June 30, 1958. We plan a substantial expansion of the program over that now in progress. We hope to complete the network of barriers in Lake Michigan, construct all necessary barriers on the United States side of Lake Huron, and begin the construction of barriers on the Canadian side of Lake Huron and on the North Channel and Georgian Bay. We hope also to have by the end of 1958 some definite answers regarding the use of poisons. This program is of course, based upon present knowledge. It was developed by experts from the two Federal agencies, and adopted by the Commission with modifications recommended by our Scientific Advisory Committee. It may well be modified in the coming months as we learn more and as we obtain advice from other agencies. The lamprey problem is an immense one. It seems possible now that there may be as many as a thousand streams in the Great Lakes with which we must deal. At the present we are working with the problem where its effects have been felt most severely—the upper lakes. In the near future, we hope to turn our attention to Lakes Erie and Ontario, and the St. Lawrence River.

The Commission has not been required to act with such speed in the development of a research program. We have not yet attempted to set down a comprehensive statement of the problems and the best ways of attacking them. At our Ottawa meeting in April of this year, we did ask the scientists from the two Federal research agencies to draw up for us a general statement of the fishery situation in the Great Lakes. We asked for this statement in order that we have a beginning point for our thinking.

The scientists reviewed briefly the status of deep-water species, pointing particularly to the effects of the sea lamprey upon the lake trout populations and the changes in the chub (cisco) populations which appear to have resulted from the disappearance of lake trout. Our attention was drawn to the random fluctuations in whitefish populations and the undetermined effect of the sea lamprey upon whitefish.

The scientists also explained that the bulk of the production of the Great Lakes is composed of shallow-water species, such as dominate the

fish faunas of Lake Erie, Lake St. Clair, Green Bay, Saginaw Bay, the Bay of Quinte, and the shallow parts of Georgian Bay. The commercial catch in Lake Erie, for example, is about equal to that of all species in the other four lakes. The smelt is believed to be a key member of the shallow-water communities of fishes, because it is competitive with other species. All of these species fluctuate to an extraordinary degree. The fluctuations make fishing in these areas acutely unstable, more so than is true of most fisheries in other areas. The causes of these fluctuations are not understood, and thus they cannot be predicted.

In conclusion, the scientists suggested that the most pressing problems of the Great Lakes fall into three general categories: finding means of restoring the lake trout as the sea lamprey control program gains in effect; learning the causes of natural fluctuations in abundance of the several species so as to predict and perhaps even control fluctuations; determining the relation between fishing intensities and yields to form a scientific basis for regulation of fishing rates which will maintain maximum sustained yields.

This is, of course, only the beginning of an attack upon the general problem facing the Commission. In the months to come, much thought must be devoted to the development of a program. In the meantime, the two federal agencies have drawn up tentative research programs which they propose to carry out during the next fiscal year. We have given our approval to these programs in order that the agencies may proceed with the procurement of funds. These programs are a nucleus about which, we hope, a comprehensive program can be developed involving the research agencies of the states and other organizations.

With regard to the comprehensive research program, the scientists pointed out to us in Ottawa: "An adequate research program cannot spring into full being in one session of a committee. The development of a good program is in itself a problem for research."

Our task is an enormous one. Our Scientific Advisory Committee is giving close study to it. The thinking, knowledge, and experience of all concerned with the fisheries of the Great Lakes will be required if the work is to be done effectively. We hope that the Commission will provide a means of bringing about a concerted attack on Great Lakes fishery problems. We hope that it will serve to emphasize the importance and difficulty of these problems, and in so doing stimulate interest and action toward their solution.

Part 3
Business Session

THE AMERICAN FISHERIES SOCIETY

Eighty-Sixth Annual Meeting

The 86th Annual Meeting of the Society was opened in the Royal York Hotel, Toronto, Ontario, at 9:00 a. m. on Monday, September 10, 1956. The agenda were as follows:

Monday, September 10

Morning: Call to order and address by the President; roll call of members; introduction of guests and visitors; address of welcome by the Honorable F. A. MacDougall in behalf of the Province of Ontario; appointment of sessional committees by the President; and reports of officers, chairmen of regional divisions, standing committees, and special committees.

Afternoon: Great Lakes Symposium; Symposium on Hydrobiology and Fish Culture; and presentation and discussion of papers.

Tuesday, September 11

Morning: Presentation and discussion of papers.

Afternoon: Presentation and discussion of papers; reports of sessional committees; election of officers, installation of the new President; concluding business.

Wednesday, September 12

Morning and Afternoon: Tour of local points of interest.

Evening: Reception in the Banquet Hall and Annual Joint Banquet in the Concert Hall of the Royal York Hotel.

REGISTERED MEMBERS IN ATTENDANCE

Albrecht, Robert Downing, Pa.
Aldrich, A. D., Fla.
Allen, Walter M., Mont.
Atton, F. Mervyn, Sask.

Bailey, Merryll M., Ohio
Bailey, Reeve M., Mich.
Balch, Howard K., Wis.
Baldwin, Norman S., Ont.
Barnickol, Paul G., Mo.
Barry, James V., Calif.
Basu, Satyen P., Ont.
Beak, T. W., Ont.
Beckman, R. W., Iowa
Benson, Norman G., Utah
Bentley, William G., N. Y.
Berst, A. H., Ont.
Bode, I. T., Mo.
Brunson, Royal Bruce, Mont.
Budd, John C., Ont.
Burdick, George E., N. Y.
Butler, George Edward, Man.
Byrd, I. B., Ala.

Callison, Chas. H., D. C.
Carbine, William F., D. C.
Chapoton, Robert B., Md.
Christie, W. J., Ont.
Clemens, Howard P., Okla.
Cooper, Edwin L., Wis.
Cooper, Gerald P., Mich.
Corbin, James Edward, Mo.
Cornell, James H., N. C.
Corson, Bernard, N. H.
Cottam, Clarence, Texas
Couldwell, George E., Sask.
Cox, E. T., Ont.
Cringan, A. T., Ont.
Croker, Richard, Calif.
Cuerrier, J. P., Ont.
Cumming, Harold G., Ont.
Cummins, Robert, Jr., Ohio
Curran, H. Wesley, Ont.

Davis, George W., Vt.
DeBoer, Marston J., Mich.
Devitt, O. E., Ont.
Dickson, Fred J., Ga.
Donaldson, Lauren R., Wash.

Eipper, Alfred W., N. Y.
Elser, Harold J., Md.
Elsey, C. A., Ont.
El-Zarka, Salah, Mich.
Eschmeyer, Paul H., Mich.

Farley, John L., Va.
Farley, William R., Ohio
Fearnow, Theodore C., Pa.
Ferguson, Robert G., Ont.
Flittner, Glenn A., Calif.
Fraser, James M., Ont.
Fremont, Charles, P. Q.
Fry, F. E. J., Ont.
Fukano, Kiyoshi G., Mich.

Galligan, James P., Conn.
Gascoyne, Rod, Mass.
Gatlin, John C., N. Mex.
Gentry, Glen, Tenn.
Gerking, Shelby D., Ind.
Gordon, Seth, Calif.
Grassl, Edward F., Mich.
Greeley, John R., N. Y.
Grim, John S., N. Y.
Gutermuth, C. R., D. C.

Hagen, Wm. Jr., D. C.
Handwork, Warren, Ohio
Harkness, William J. K., Ont.
Hartman, Philip Henry, Ont.
Hartman, Wilbur Lee, N. Y.
Hassler, William W., N. C.
Hatch, Richard W., N. Y.
Hazzard, A. S., Pa.
Henderson, Croswell, Ohio
Hendrickson, E. F., Wyo.
Hile, Ralph, Mich.
Hollingsworth, Norman B., Ont.
Hooper, Frank F., Mich.
Hourston, William Roderick, B. C.
Houser, Alfred, Okla.
Hutchinson, Samuel J., Ore.

Ide, F. P., Ont.
Irizawa, Kenneth K., Ont.

Jacob, Buddy L., Wis.
Janzen, Daniel H., Minn.
Jenkins, Robert M., Okla.
Johnson, Raymond E., Minn.
Johnson, Ronald P., Sask.
Jones, Robert Andrew, Conn.
Joslin, Verne E., Minn.

Karvelis, Ernest G., Conn.
Kennedy, W. A., Ont.

King, John, Okla.
Kinney, Edward C., W. Va.
Kortright, F. H., Ont.
Krumholz, Louis A., Fla.

Lagler, Karl F., Mich.
Langford, R. R., Ont.
Lawrence, William M., N. Y.
Laythe, Leo L., Ore.
Leonard, Justin W., Mich.
Lewis, Lawrence J., Mich.
Loftus, Kenneth H., Ont.
Luethy, Don R., Fla.
Lund, William A., Jr., N. Y.

MacDougall, F. A., Ont.
MacKay, H. H., Ont.
Maciolek, John A., Calif.
Madden, K. M., Iowa
Madsen, M. J., Utah
Mair, W. Winston, Ont.
Mayall, Kenneth M., Ont.
McBroom, James T., D. C.
McCabe, Britton, Mass.
McCarraher, D. B., Neb.
McCauley, R. W., Ont.
McReynolds, Harold E., Ind.

Meehean, O. Lloyd, D. C.
Miller, Frank, Wis.
Miller, Richard B., Alberta
Miller, Robert R., Mich.
Millest, R. H., Ont.
Moffett, James W., Mich.
Mookherji, Piyushansu Sekkar, Ont.
Motl, Laurence F., Wis.
Moyle, John B., Minn.
Muir, Barry S., Ont.
Mullan, James W., Mass.

Needham, Paul H., Calif.
Neth, Paul C., N. Y.
Nursall, J. R., Alberta

Omstead, Leonard R., Ont.

Papier, David, Ohio
Parr, Sam, Ill.
Pasko, Donald G., N. Y.
Pautzke, Clarence F., Wash.
Pavcek, Paul L., Wis.
Pough, Richard H., N. Y.
Prevost, Gustave, P. Q.
Pritchard, A. L., Ont.
Raney, Edward C., N. Y.
Rawson, D. S., Sask.
Rhynas, Philip O., Ohio
Roach, Lee S., Ohio
Roelofs, Eugene W., Mich.
Ruhr, Clifford E., Tenn.
Rutherford, Robert M., D. C.
Ryder, Richard A., Ont.

Scattergood, Leslie W., Me.
Schneberger, Edw., Wis.
Schwartz, Frank J., W. Va.
Scott, David P., Ont.
Scott, Wm. B., Ont.
Seaman, Elwood A., Va.
Seguin, Louis-Roch, P. Q.
Shoemaker, Carl D., D. C.
Simpson, James C., Idaho
Smith, Stanford H., Mich.
Smith, Stuart B., B. C.
Sneed, Kermit, Okla.
Snieszko, Stanislas F., W. Va.
Solman, Victor E. F., Ont.
Speaker, E. B., Iowa
Sprecher, George E., Wis.
Steen, M. O., Neb.
Stevens, Richard I., N. Y.
Stone, Udell B., N. Y.
Stroud, Richard H., D. C.
Swenson, Edwin A., Jr., Conn.
Swenson, Hjalmar, Minn.
Swift, Ernest, D. C.
Swift, Lloyd W., D. C.
Swingle, H. S., Ala.

Thomas, Ronald C., Alberta
Thompson, Fred A., N. Mex.
Thompson, William H., Okla.
Thorpe, Lyle M., Conn.
Tunison, A. V., D. C.

Underhill, A. H., N. J.

Van Meter, Harry D., W. Va.
Vladykov, Vadim D., P. Q.
Voigt, L. P., Wis.
Voigt, William Jr., Pa.

Wade, Gerry, Me.
Walden, Francis A., Ont.
Wallen, Irvin Eugene, D. C.
Waters, Thomas F., Mich.
Watkins, H. B., Alberta
Webster, Dwight A., N. Y.
Weir, J. Charles, Ont.
Weir, Robert A., Ont.
Werner, W. H. R., Ont.
Westerman, Fred A., Mich.
Westman, James R., N. J.
Wilkinson, J. T., Mich.
Wright, Stillman, D. C.

Yoder, C. Troy, Mich.
Youngs, William D., N. Y.

OPENING REMARKS OF THE PRESIDENT

SOME HIGHLIGHTS IN THE HISTORY OF THE AMERICAN FISHERIES SOCIETY

George E. Sprecher

Today the American Fisheries Society is enjoying the excellent hospitality of Canada for the seventh time. It is significant that our meeting is located just about 40 miles west of the famous Wilmot's Creek at Newcastle on which one of the first American fish hatcheries was established by the Canadian Government in 1868. Samuel Wilmot, one of the first honorary members of this Society and Canada's first Superintendent of Fish Culture, began hatching salmon eggs at this location three years before and received financial assistance from the Dominion Government in 1867.

Thirteen years earlier, on February 22, 1854, the first baby brook trout artificially hatched on the North American continent were produced by Dr. Theodatus Garlick of Cleveland, Ohio. This is also the first American propagation record for any species of fish and the beginning of a chain reaction because the public's interest was aroused by this new opportunity. Dr. Garlick's report states that he had read an article on the possibilities of artificial propagation of fishes in the *National Intelligencer* of 1853 and no doubt many others read this same article. It is of interest to note that the parents of Dr. Garlick's fish were caught at Sault Ste. Marie and Port Stanley in the fall of 1853 and were as close to being "International" fish as possible!

Because of this International background to the origin of the Society I am taking this opportunity here in Toronto to call your attention to the work of some of the founders of this organization and also to some of the obstacles which were overcome by our illustrious predecessors. Although the Dominion Government's fish propagation work began several years before that of the United States Fish Commission in 1872, it seems that private individuals and their state and provincial governments in both countries developed this new opportunity simultaneously. In 1856 Massachusetts set up a commission to study facts regarding artificial propagation of fish and the Commissioner of the Crown Lands of Canada recommended artificial fish culture to prevent the reduction of the salmon fisheries of the Province of Quebec. Both the New Hampshire and Vermont Legislatures issued reports on the subject the following year while at the same time Richard Nettle of Quebec began hatching trout and secured official permission to artificially rear salmon. By 1864 the famous Seth Green of New York had established his private fish hatchery and three years later Massachusetts established a hatchery on the Connecticut River for artificial propagation of shad. At this

time a published report calculated a profit of about a half million dollars in four years from artificial trout propagation on a large scale.

Another pioneer fish culturist was the Canadian, James Nevin, who served over 40 years as Wisconsin's first Superintendent of Fisheries. He started work at the Newcastle hatchery in 1869 and was a close associate of Samuel Wilmot who answered the call to attend a meeting on December 20, 1870, in New York City to consider organization of a permanent association. Reverend William Clift, a trout breeder from Mystic Bridge, Connecticut, had proposed this idea and several other private breeders of brook trout sponsored the call with him. He became President of the new organization for the first three terms.

The call for this meeting stated that it was partly "for consultation for protection of our interests," but it is reliably reported that after the group assembled there was little talk of regulating the price of trout for the market. Instead, they organized the American Fish Culturists' Association "to promote the cause of fish culture" and related interests. As a result of this meeting and previous to the second in 1872, they planned a live fish exhibit at the New York Poultry Show, publicized their first meeting, distributed a request for information on American salmon to assist Professor Agassiz of Cambridge, Massachusetts, with a proposed book, recommended research on the genetics of the blind fish of Mammoth Cave, urged International action for the removal of obstructions to fish in the St. Lawrence River and recommended publication of a list of American fish in order to develop more consistent nomenclature. This detail is mentioned because it shows the broad interest of this organization from the very first.

This group of charter members included such men as Seth Green and Fred Mather of New York and Livingstone Stone of New Hampshire. All of them eventually became important on either state or federal fish commissions and all of them wrote books on the subject. Both Green and Mather were awarded gold medals for their early contributions and inventions for fish breeding.

Although the U. S. Fish Commission was organized in 1871 with Spencer F. Baird as it first Commissioner, their original assignment was strictly one of fisheries investigation. The new American Fish Culturists' Association successfully urged Congress to increase the Commission's appropriation for the establishment of at least two fish hatcheries the following year. This was the beginning of mutual cooperation which at times may have been responsible for their successful continuation.

So far as vital statistics are concerned, the Society's name was changed to the American Fish Cultural Association in 1878 so as to include in the Constitution reference to "the treatment of all questions regarding fish, of a scientific and economic character." The present name of "American Fisheries Society" was given birth at an unannounced business meeting in Washington, D. C., on board the U. S. Fish Commission's steamer "Fish Hawk" as it moved on the Potomac River during the afternoon of May 14, 1884.

The proceedings were not without pain, for pioneer members such as Mather, Roosevelt and Stone strongly opposed the change. In many ways this was a memorable meeting, for Professor Baird had called a special gathering of State Fish Commissioners at his office for the first time and the Society adjourned to pay their respects to President Arthur during the sessions. Later, on December 16, 1910, the Society was incorporated in the District of Columbia—"for a period of nine hundred and ninety-nine years."

During its first decade of existence the Society was closely associated with the Fulton Fish Market in New York City as a headquarters location and often held the annual meeting in the rooms of the Fulton Fishmongers' Association. Also during this period, it was traditional to have a huge annual banquet featuring dozens of special fish dishes.

The newspapers played an important role in the Society's growth and in the early days its activities were front page news. On May 5, 1885, the *Washington Post* reported that "the members will probably call on the President today." The following year on April 13 the *Chicago Tribune* also gave front page notice of the Society's first meeting "held in the West." This same day the *Chicago Times* reported that "The membership includes all the United States Fish Commission, nearly all the State Commissioners and the leading scientific men of the East . . . It is expected that no less than nine hundred prominent members will be in attendance from all parts of the land, as the Society embraces no less than thirty-two states and territories." The next day this paper reported: "Owing to the small number present, the meeting adjourned until 2:30 after the transaction of minor routine business."

At this time the Central Fish Cultural Association which organized in 1879 and held a second meeting in 1880, dissolved and joined our national organization. About 1920 another amalgamation took place when the Nation Association of Fish Commissioners, previously known as "Shellfish Commissioners," joined the Society. It is of interest here to note the history of the International Association of Game, Fish and Conservation Commissioners which meets in conjunction with the Society each year. This group was orginally founded by W. F. Scott of Montana, who called a meeting of the National Association of Game and Fish Wardens and Commissioners at Yellowstone National Park on July 20, 1902. By a coincidence, their 1912 meeting at Denver was held a short time before that of the Society. Because of the overlapping of interests and need for coordination, they offered to meet jointly with the Society in future years.

In the early days the original Association limited its membership with a policy requiring election at annual meetings, distribution of the TRANSACTIONS only to members with no sale of extra copies and a high $5.00 membership fee for part of the time. Another deterrent to joining was the fact that *Forest and Stream* magazine published all the papers and most of the procedings even before the TRANSACTIONS appeared and there was

little incentive to join. While attendance at these early meetings varied from 20 to 200, including visitors, a low point in attendance occurred at the first really Western meeting at Omaha, Nebraska, in 1898 when the membership voted to reduce the dues to $1.00 a year by a 10 to 5 ballot. This indicated that only 15 voting members were present.

This brings up the question of finances and members, and it must be admitted that with a $1.00 membership fee the Treasurer's balance of $401.26 quickly dwindled to a deficit of $62.65 by 1904. Also, another 1898 decision to sell the old TRANSACTIONS at 25 cents each rapidly depleted that reserve. When the 1904 meeting increased this charge to 50 cents and the dues to $2.00 there was one other favorable sign—the Society's membership had grown to 453 in active status. Over the years the treasury was "in the red" a number of times. While the Treasurer of 1905 had to advance the Society $250 in order to meet its obligations, the publication of the 40th Anniversary TRANSACTIONS was so costly there was an item of $563.65 due the Treasurer in 1911. The Society still was over $900 in debt the following year, but quickly recovered and paid its debts.

From that date onward, with the exception of the World War II period, the record is one of continuous growth with a high point at the end of the fiscal year in 1956 of 1,734 members and a net worth of $18,633.32. Unfortunately, the Society was slow in holding meetings where the membership was low. Not until 1915 did they meet in California, for which the Society received a welcome dividend, Captain Jefferson F. Moser, General Superintendent of the Alaska Packers' Association, secured 50 patron members at $50 each to help build up the Society's Permanent Fund which has since been very beneficial in times of financial need. Also unfortunate was the fact that not until the 50th Anniversary meeting was the Society treated to Canadian hospitality at Ottawa. There was a great increase in Canadian membership and their participation in the Society's activities from that time onward. Today we have grown to include Western, Southern and Northeastern divisions and have a North Central division in process of formation.

From the earliest meetings there was an International aspect to the American Fisheries Society. Through the medium of corresponding members the Secretary was in contact with fisheries authorities throughout the world. This also was true of the honorary members selected. In 1882 these included both Professor Thomas H. Huxley of England and His Royal Highness Frederick William, Crown Prince of Prussia and of Germany.

Returning now to some of the sidelights of the Society's early years it is interesting to note that as the Association grew and prospered, so also the idea of artificial propagation was extended throughout the land from New York to California. There seemed to be competition to see which group could first introduce some exotic fish, propagate the Michigan grayling or first stock California salmon in Lake Ontario or shad in

the Sacramento River. There are some humorous incidents which resulted —and many pathetic mistakes. One interesting anecdote reports that the Michigan grayling won a blue ribbon at the 1874 State Fair because it was the most "sprightly fish exhibited" after being shipped 400 miles. This resulted in a published report that "it will thrive where other fish species cannot." In this same year a private individual and a state fish commission were responsible respectively for stocking carp in Sonoma Creek near San Francisco and 36,000 eels in Buffalo Creek above the Niagara Falls.

So far as the history of fish culture in America is concerned, we are fortunate that a very complete record of the early days has been preserved in the Society's TRANSACTIONS and in *Forest and Stream* magazine which began in August, 1873. The following year it became the Association's official organ and published all the papers before other magazines secured them or the official TRANSACTIONS were issued. Although this official connection was quickly severed the next meeting, *Forest and Stream* continued to publish complete reports of the activities of most fish commissions and the Association.

In the work of fish propagation in this early day, there were both signs of wisdom and of ignorance. Livingstone Stone stated that success depended on ample quantities of the proper kinds of water; Fred Mather cautioned that these vast numbers of fish were being stocked "with but little consideration of the many delicate conditions necessary to their future growth," and Seth Green complained that people seem to think that fish can live on water while "the great secret of success in this work is in putting fish in the waters suited to them."

The International movement for the propagation, transportation and stocking of fish of all kinds soon developed several interesting relationships. There were educational live fish exhibits at most of the larger fairs climaxing at the World's Columbian Exhibition in Chicago in 1893. The railroads were sold on the proposition that more fish were good for their business and they subsidized the program by transporting state and national "fish cars" free of charge. Local sportsmen's clubs raised trout for stocking and also sold them on the market for profit. The commercial fishermen supported the program hopefully. Everything went well until the enormous numbers of fry and small fish stocked didn't show up in the nets as promised.

Even if all the early fish stocking work had failed, the movement had many significant subsidiary values which no doubt were even more important. The desire to see these fish succeed in their new waters brought immediate attention upon the obvious faults in the waters themselves. From the first there was a demand that the migratory fish be favored with fishways in all dams—or that there be no dams at all. When a stocking of fish failed, the blame was often placed on pollution of the water, fish poaching or commercialization. This resulted in the organiza-

tion of national, state and provincial fish and game protective leagues and the beginning of the conservation movement in America. In fact it was the fish commissions that often did the first experimental propagation work on pheasants and other game animals.

We can be proud to say that our Society was a leader and active participant in this early trend for the preservation and restoration of wildlife and its habitat. Our TRANSACTIONS in the first decade carry statements by Fred Mather on the "poisoning and obstructing of waters . . . by the greed of a few men who make sewers of our brooks and rivers"; by Samuel Wilmot on "the baneful effects of all kinds of sediment and of deleterous substances from mills, manufactories and manures" and support of a resolution by Charles Hallock of New York for simpler, more uniform laws for the protection of fish and game partly to prevent illegal sale in adjacent states. The Society's President in 1874, Robert B. Roosevelt, was also Vice-President of the New York Society for the Protection of Game which called a national convention on this subject in 1874.

Because most of the Society's early publications stressed the propagation of fish, it may be mistakenly believed that nothing else was considered. Actually, from almost the beginning, there was an effort made toward research and management at least in the recognition of their importance. Samuel Wilmot punched holes in the dorsal fin and tail of salmon as early as 1865 in his effort to study their migratory habits in Lake Ontario. In 1875 Thaddeus Norris of Pennsylvania carefully studied the native habitat of the Michigan grayling in relation to its possible stocking in Eastern waters. Research into fish diseases of necessity started almost simultaneously with propagation.

In 1874 George Jerome of the Michigan Fish Commission more or less predicted present day management activities with his statement on the productivity of waters: "Let it be cleared up, plowed, manured, so to speak, scientifically tilled, and the choicer varieties of stock introduced, and we will prove a given acreage of water to be equal in production and value to the same acreage of land." That same year A. S. Collins of New York, the first man to successfully propagate the Michigan grayling, modestly questioned their superiority to brook trout with the acid test when he commented: "It is true they have a magnificent dorsal fin, but that can't be fried to any advantage!"

In 1883 Fred Mather read a paper on the habits of sunfish and plans for their wholesale destruction by dynamite or lime in waters where they were detrimental to fish culture. At the same time New York's fish culturist, A. N. Cheney advocated the planting of food for fish prior to placing them in ponds or streams. By 1885 Col. Marshall McDonald, U. S. Fish Commissioner, had clearly outlined research needs in his talk on "Objective Points in Fish Culture." Four years later Fred Mather surveyed two lakes on Long Island for possible fish management with the assistance of Bashford Dean, a Columbia College professor, who in-

vestigated the botany and invertebrates of the waters. This was the beginning of the era of studies by such men as Professors E. A. Birge of Wisconsin, S. A. Forbes of Illinois and C. W. Nash of Canada.

Some of the first efforts toward the conservation of forests were founded on arguments for a constant clean water supply for fish life. In 1889 the New York Commissioners of Fisheries were among the leaders in urging acquisition of the Adirondack Forest Preserve. The Society's TRANSACTIONS also carry early reports such as Filibert Roth's "Reforestation and the Fisherman," and those on forest protection and water supply conservation by Honore Mercier of Quebec. These were the beginnings of present day watershed management.

In this short summary it is possible to cite only a few examples indicating the trends and no effort is made to mention all who were pioneers in this field. However, some mention should be made of those who had important roles in some of our early International fishery treaties and their public acceptance. Canada's first Commissioner of Fisheries, W. F. Whitcher, who also was on the Society's first Executive Committee, published a masterful synopsis on fishery treaties between Britain and the United States in the Society's first year. Also, in 1891, past-President Robert B. Roosevelt served as chairman of an International Conference on Great Lakes Fisheries held in New York City for the purpose of discussing uniform regulations and other fishery problems. Subsequent meetings were held that year at Rochester, New York, and Hamilton, Ontario. Present members have been active in more recent treaty conventions.

From a legislative and legal standpoint there were other important early day highlights including the Society's support from the first on Supreme Court battles to decide the rights of the public to manage and harvest the fisheries in public waters. In 1890 the Society strongly opposed a move to fill top positions in the U. S. Fish Commission with political appointees and two years later they urged all states' Legislatures to continue their Fish Commissions even though the U. S. Fish Commission was distributing fish on a nation-wide basis. A resolution adopted at the Quebec meeting in 1924 urged the United States Government to carry out its obligations in the planned International Commercial Fishing Treaty with Canada. From an early date regular committees worked on these subjects of International and National-state relations. A milestone in legal interpretation was General Edwin E. Bryant's 1901 report on "The Power of the State to Regulate Fisheries and the Taking of Fish." His paper was so timely that the Society published it immediately as a separate pamphlet and showed their appreciation by electing him President. The Society, which has always displayed an active interest in Legislative matters, continues to support International Treaties and Interstate Compacts.

As most members are aware of the many recent accomplishments and activities of the Society, only brief mention will be made of a few highlights. Since the recommendation by Seth Gordon in 1933 that an Ameri-

can Game-Fish Policy be developed, this type of document eventually was prepared and has served a good purpose in recent years. Another valuable contribution of a Society committee was the "List of Common and Scientific Names of the Better Known Fishes of the United States and Canada." As has been shown, this project started in 1870 and is still in progress. Also, much good work is constantly performed by the Society's regular and special committees aimed at betterment of the fisheries and the positions of those who work in this field.

So far as the mechanics of Society operation are concerned, these past 86 years have had their ups and downs, their humor and their pathos. In actuality this is the 81st annual meeting or the 82nd meeting if a special one held on October 6, 1876, in conjunction with the Philadelphia Centennial Exhibition is counted. Four annual meetings were cancelled during the recent war period. Counting the 1955 TRANSACTIONS, a total of 84 issues containing more than 20,000 pages of material have been issued. There would be 85 issues if proceedings the first two years had not been combined in one publication. To adjust for this, a Society President in 1909 ordered the skipping of both the 1909 date and reference to the "Thirty-eighth Annual Meeting" to successfully confuse librarians throughout the world. Some of these TRANSACTIONS are over 500 pages, while the smallest for the fifth annual meeting in 1876 is but 20 pages. The TRANSACTIONS were issued on a quarterly basis from December, 1914, until September, 1920.

This brief review of the Society's history must include a recognition of the fact that it is inadequate and has overlooked many significant events. A survey of the numerous resolutions adopted over the years chronicles these fishery needs. The fact that many of them have been accomplished is a credit to the Society's efforts. Two such resolutions cited as examples are: one in 1898—to urge the U. S. Fish Commission to establish a Great Lakes Fisheries Scientific Laboratory and another in 1919—to recognize the first courses in fish culture and fisheries work at the State University of Washington and Cornell University respectively.

Before concluding this paper I want to express my appreciation to Walter E. Scott of Wisconsin for his diligent search of original sources for the historical material included in this report. I also want to thank our librarian, Howard Tanner, for the loan of the first 21 volumes of the TRANSACTIONS which provided many important facts on the early history of the Society.

Now in conclusion, I wish to quote from the statement of past President of the Society, Carlos Avery of St. Paul, Minnesota, in 1920. At our first meeting in Canada President Avery observed: "We in the United States are not so different from you Canadians. We are all of one blood. We are brothers; we come from the same race; we speak the same language; we have similar laws and similar institutions, similar ambitions and similar problems. We ought to live side by side as nations throughout the coming

years in the utmost harmony and with the best of good feeling." With this I wholeheartedly agree and feel it is assurance for our continued cooperation in the Society's business.

In addition, let me assure you that we will need the cooperation of all nations to meet the ever increasing demands of the human race on our fishery resources. The shrinking work week and th ecorresponding increased demand for recreation by countless millions of people who never before had the opportunity to enjoy sport fishing and who now appear in ever increasing numbers compels every member of this Society to recognize his responsibility to do his utmost to improve this ancient and honorable pastime. This is a high responsibility but we have the talent and the know-how within the membership of the Society to accomplish it.

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APPOINTMENT OF SESSIONAL COMMITTEES

Nominating

W. Mason Lawrence, New York, *Chairman*
Lauren R. Donaldson, Washington
Sam A. Parr, Illinois
James H. Cornell, North Carolina
A. L. Pritchard, Ontario

Resolutions

A. S. Hazzard, Pennsylvania, *Chairman*
A. D. Aldrich, Florida
J. P. Currier, Ontario
Frederick A. Thompson, New Mexico
Stillman Wright, Washington D.C.

Auditing

Edward Schneberger, Wisconsin, *Chairman*
Kenneth H. Loftus, Ontario
Hjalmar O. Swenson, Minnesota

Time and Place

William Voight, Jr., Pennsylvania, *Chairman*
Charles O. Hayford, New Jersey
Karl F. Lagler, Michigan
Lee S. Roach, Ohio
Arnie Soumela, Washington, D.C.

Publicity

H. H. McKay, Ontario, *Chairman*
Norman Baldwin, Ontario
Charles Wier, Ontario

REPORT OF OFFICERS

REPORT OF THE SECRETARY-TREASURER

EVERETT B. SPEAKER

It would probably suffice merely to state that the American Fisheries Society is in excellent financial condition and that the membership is growing each year. I am sure, however, that many of the members would be disappointed if the customary statistical analysis were not given at this time.

On July 1, 1956, there was a balance on hand of $5,124.57 in the General and Permanent Funds, and a total of $13,508.75 in negotiable securities, bringing the total worth of the Society to $18,633.32, not including the volumes of the TRANSACTIONS stored with the Librarian.

As of September 1, 1956, the bank balance of the Society is $10,870.40, or a total of $24,379.24 including the securities. It should be pointed out, however, that Volume 85 of the TRANSACTIONS, now in press, is yet to be paid for.

One would be remiss in his duty if he failed to recognize the extreme effort put forth by our distinguished Vice Presidents, Clarence Pautzke and Homer Swingle, in the all-out membership drive. At the beginning of the Augusta meeting last year we had a total membership of 1,655. From that date to July 1, 1956, 172 new members were approved by the President and Secretary. On September 1, 1956, 88 members were dropped for non-payment of dues, demit, death, etc. The Secretary brought 36 applications to the meeting for approval, and 1 new member has been added since our arrival in Toronto, bringing our current membership to 1,776.

Co-operation from all officers and members of the Executive Committee was splendid this year, and I am particularly grateful to our President, George Sprecher, for unlimited help and counsel. Our Program Chairman, Dr. Harkness, and his Committee have worked night and day since the close of the last meeting to bring you one of the most interesting programs in the history of the Society.

The three Divisions of the Society have been very active and have accomplished much during the past year. It is hoped before the close of this meeting a new Division, the North Central, will be added to the list.

With your permission, a quick break-down will be given of the current financial status of the Society, and the proposed budget for the coming year.

REPORT OF RECEIPTS AND DISBURSEMENTS

July 1, 1955, to June 30, 1956

GENERAL FUND		1955-56
Balance on hand, July 1, 1955		$ 4,312.72
Receipts:		
Annual Dues		
Individual memberships		
For the year 1952–53	$ 9.00	
1953–54	90.00	
1954–55	427.50	
1955–56	5,525.75	
1956–57	307.80	
1957–58	9.00	
1958–59	9.00	
1959–60	9.00	$ 6,387.05
State memberships		
For the year 1954–55	$ 20.00	
1955–56	1,340.00	
1956–57	80.00	$ 1,440.00
Library memberships		
For the year 1953–54	$ 8.00	
1954–55	19.50	
1955–56	387.50	
1956–57	52.00	$ 467.00
Club memberships		
For the year 1954–55	$ 10.00	
1955–56	220.25	
1956–57	10.00	$ 240.25
Sale of TRANSACTIONS and Special Publications		$ 1,204.50
Sale of Index		$ 35.50
Total Receipts		$ 9,774.30
Balance July 1 Plus Total Receipts		$14,087.02
Disbursements:		
Printing TRANSACTIONS	$5,908.65	
Other printing	660.67	
Postage and supplies	335.02	
Indexing TRANSACTIONS	150.00	
Reporting services (Seattle)	298.00	
Reporting services (Augusta)	376.54	
Insurance	188.24	
Fidelity Bond	18.75	
Clerical Services—Marj. Wright	151.56	

Travel expenses—Secretary to mid-winter Executive Committee meeting	200.53	
Dues to Natural Resources Council	50.00	
Purchase of TRANSACTIONS	66.75	
Miscellaneous	1.50	
Less: Total Disbursements		$ 8,406.21
Transfer to Permanent Fund, March, 1956		1,000.00
Gross Balance, General Fund, June 30, 1956		$ 4,680.81
Less: Bank debit memorandums		22.45
Net Balance, General Fund, June 30, 1956		$ 4,658.36

PERMANENT FUND

		1955-56
Balance on hand, July 1, 1955		$ 840.32
Receipts:		
Individual Life Memberships	$ 150.00	
Dividend Income		
Consumers Power Co.	63.80	
Central Illinois Light Co.	15.05	
Plus: Total Receipts		$ 228.85
Transfer from General Fund, March 1956		1,000.00
Balance, July 1, plus Receipts and Transfer		$ 2,069.17
Disbursements::		
Assistance Augusta meeting	$ 800.00	
Purchase of 12/20 share Consumers Power Co. stock	30.46	
Purchase of Rights—Central Illinois Light Co.	1.00	
Purchase of stock—Central Illinois Light Co.	51.50	
Purchase of Government Savings Bond	720.00	
Less: Total Disbursements		$ 1,602.96
Net Balance, Permanent Fund, June 30, 1956		$ 466.21

RECAPITULATION

Net Balance, General Fund, June 30, 1956	$ 4,658.36
Net Balance, Permanent Fund, June 30, 1956	466.21
Net Balance, Both Funds, June 30, 1956	$ 5,124.57

FOR GENERAL FUND

Gross Balance, General Fund, June 30, 1956		$ 4,680.81
Less: 1955–56 Bank debit memorandums		
7/20/55 Bank exchange charges	$ .45	
7/22/55 Check returned—drawer dead	4.50	
7/26/55 Check returned—Account closed	4.50	
8/26/55 Check returned—Account closed	4.50	
8/31/55 Check returned—Account closed	4.50	
10/5/55 Check returned—Account closed	4.00	22.45
Net Balance, General Fund, June 30, 1956		$ 4,658.36

RECONCILIATION OF RECEIPTS TO DEPOSITS
July 1, 1955, to June 30, 1956

Total deposits per bank statements		$10,003.15
Total receipts per cash receipts book		
General Fund	$9,774.30	
Permanent Fund	228.85	
Total Receipts to June 30, 1956		$10,003.15
Balance per bank statement June 30, 1956		$ 5,148.70
(Iowa State Bank, Des Moines, Iowa)		
Less: Uncancelled checks		
Check No. 245	$ 1.00	
No. 252	3.40	
No. 253	6.12	
No. 255	13.61	
Total		$ 24.13
Balance per check book		$ 5,124.57

SECURITIES HELD JUNE 30, 1956

(1) U. S. Government Savings Bonds

Number	Date Purchased	Mature Value	Value
D682395F	8/29/49	$ 500.00	$ 417.50
M1610061F	8/29/49	1,000.00	835.00
D702345F	12/15/50	500.00	404.50
M1703542F	12/15/50	1,000.00	809.00
M1773328F	10/31/51	1,000.00	786.00
M1773329F	10/31/51	1,000.00	786.00
M1773330F	10/31/51	1,000.00	786.00
M18441J	9/26/52	1,000.00	768.00
M18346J	9/26/52	1,000.00	768.00
M18347J	9/26/52	1,000.00	768.00
M18348J	9/26/52	1,000.00	768.00
M18349J	9/26/52	1,000.00	768.00
M18350J	9/26/52	1,000.00	768.00
M18351J	9/26/52	1,000.00	768.00
M18352J	9/26/52	1,000.00	768.00
M208433J	6/27/56	1,000.00	720.00
		$15,000.00	$11,688.00

(2) Consumers Power Company		
G-6085	28 shares at 47⅝	
E157859	1 share at 47⅝	
G164617	1 share at 47⅝	$ 1,428.75
(3) Central Illinois Light Company		
B-1752	6 shares at 56	
B44568	1 share at 56	$ 392.00
Total		$13,508.75

PROPOSED BUDGET FOR 1956-57 FISCAL YEAR

GENERAL FUND

Balance on hand July 1, 1956		$ 4,658.36
Estimated Receipts		
Annual dues	$ 8,500.00	
Sale of publications	1,200.00	
Total estimated receipts		9,700.00
Net estimated income		$14,358.36
Estimated Disbursements		
Printing of Transactions—Vol. 85	$ 6,200.00	
Other printing	700.00	
Clerical services	200.00	
Postage and supplies	400.00	
Editing	175.00	
Reporting services	400.00	
Insurance	200.00	
Fidelity Bond	62.50	
Travel expense	300.00	
Dues—Natural Resources Council	50.00	
Miscellaneous	200.00	
Total estimated disbursements		$ 8,887.50
Net Estimated General Fund Balance—6-30-57		$ 5,470.86

PERMANENT FUND

Balance on hand July 1, 1956	$ 466.21	
Value of securities held July 1, 1956	13,508.75	
Estimated Receipts		
Dividends	75.00	
Increment on U. S. Government Bonds	260.00	
Net Estimated Permanent Fund Balance, June 30, 1957		$14,309.96
Net Estimated Balance, Both Funds, June 30, 1957		$19,780.82*

*Providing Volume 86 does not appear within the fiscal year ending June 30, 1957.

REPORT OF THE LIBRARIAN

HOWARD A. TANNER

During the period of September 1, 1955 to September 1, 1956, the Office of the Librarian has sold 335 volumes of the TRANSACTIONS worth $1,262.50, 185 copies of Special Publication No. 1, worth $46.25, 51 paper bound indexes—1929-1952 worth $51.00, 10 paper bound indexes—1872-1928 worth $10.00 and 4 cloth bound indexes—1872-1928 worth $6.00. These volumes and publications have a value of $1,375.75. In addition there were $289.25 in accounts outstanding from the period prior to September 1, 1955 for a total in accounts receivable of $1,664.90. A total of $1,178.50 has been forwarded to your Treasurer, Mr. Speaker. Seven volumes worth $31.50 have been returned to us and accounts outstanding total $455.00.

This has been the first year during which the duties of the Librarian's Office have been assumed by a library assistant from the regular Colorado A and M College Library. This generous assistance has made possible the retention of the office of Society Librarian by myself, thereby saving the Society the cost of moving our three to four tons of volumes. In return for their assistance the Head Librarian, Dr. Hodgson, has requested that the members of the Society wishing to dispose of all or portions of their personal libraries either donate them to the fisheries collection at the Colorado A and M Library or give his library an opportunity to purchase private fisheries libraries at a reasonable cost. May I add this request that the Colorado A and M Library be placed on your reprint and publishing mailing lists.

It should also be mentioned that the Colorado A and M Library has arranged the transfer of our stored volumes from an unheated, untended garage to a permanent fire-proof building. This will eventually result in a considerable savings on our fire insurance. I wish to report to the Society that this arrangement whereby the routine duties of the Librarian's Office are handled by the College Library assistant but under which the Society's Librarian retains responsibility, audits reports and inventories, retains the permanent set of TRANSACTIONS and replies to correspondence containing technical questions, has proven very satisfactory from my standpoint. Under this arrangement I am willing to continue to serve you as your librarian.

REPORT OF THE CHAIRMAN OF THE SOUTHERN DIVISION

NORMAN E. BENSON

The Southern Division of the American Fisheries Society met October 7-10, 1956, at Little Rock, Arkansas, and 51 members attended. The

general chairman of the fish sessions was Dr. James Stevenson. Panels were conducted on large impoundment management and on pollution. The pollution panel included: Dr. W. H. Irwin, Kenneth Biglane, Eugene Surber, and Dr. Clarence Tarzwell. The large impoundment panel included Andrew Hulsey, Ellis Carter, Carlos Fetterolf Jr. and David Graves.

Resolutions passed by the Southern Division included: (1) that the "Names of Fishes" committee of the parent society consult with a committee from the Southern Division where the fishes are indigenous to that region before officially adopting a common name, and that the present names be reviewed before republication, and (2) that efforts be made to establish research by Saltonstall-Kennedy funds for fish culture in rice fields.

Much discussion was held on commercial culture of food fishes and on new methods of weed control. An effort will be made during the coming year to extend membership. The new officers installed were Chairman, Carlos Fetterolf Jr., Tennessee Game and Fish Commission, Vice Chairman, Jefferson Fuller, South Carolina Department of Wildlife Resources, Secretary-Treasurer, Jack Snow, U. S. Fish and Wildlife Service. A special discussion was held on the regulation and management of commercial fishing in large reservoirs.

REPORT OF THE CHAIRMAN OF THE WESTERN DIVISION

Oral report of activities of the Division given.

REPORT OF THE CHAIRMAN OF THE NORTHEASTERN DIVISION

Oral report of activities of Division given.

ORGANIZATION OF THE NORTH CENTRAL DIVISION

RAYMOND E. JOHNSON

A general discussion held among midwestern members of the Society at St. Louis, Missouri, in December 1954, ended in agreement that a North Central Division should be organized along certain definite lines. An interim committee prepared by-laws and the first formal organization meeting was held at Lafayette, Indiana, on December 13, 1955. The by-

laws were approved there and were later accepted by the parent Society at Toronto in September, 1956. The new Division was a reality.

The second formal meeting was held at Lansing, Michigan, on December 10-12, 1956 as a part of the 18th Annual Midwest Wildlife Conference. Society President Pautzke attended all gatherings and gave his views on the opportunities open to this Division. In addition to the many fisheries papers, an important part of the meeting was a discussion led by Dr. Karl F. Lagler, University of Michigan, on professional standards, ethics, and status of fishery workers.

Officers elected for the coming year are: Chairman, Dr. E. W. Schneberger, Wisconsin; Vice-Chairman, Dr. K. D. Carlander, Iowa State College; Secretary-Treasurer, Dr. S. D. Gerking, Indiana University. The Division is fortunate in having a slate which can represent it at various national meetings, and which has the experience necessary to organize and launch several regional activities. The next meeting will be at Milwaukee during the early weeks of December, 1957.

REPORT OF STANDING COMMITTEES

NATIONAL–STATE RELATIONS

WILLIAM H. THOMPSON

It is felt that the Society should take a more active part in National-State relations and especially some part in national legislation which might vitally affect the interest of all members of the Society. It seems that we more nearly operate as a historical society which records the facts rather than as an active group promoting administrative measures for the betterment of fisheries. It is my feeling that future committees might even suggest to States as well as the Federal Government a broad pattern of model legislation dealing with fishery administration.

Too, why should not the Society through its committee express some interest in the continuation of good and sound legislation in the various states when trouble arises as the result of politics. A few well chosen words directed to the proper places might well prevent the destruction of sound programs on both the state and national level.

Fishery workers on the whole are reluctant to press for improvement of their lot and accept too gracefully the will of other administrators. Politics whether we like it or not governs all of our actions. If as a group we continue to remain aloof, how can we expect to be treated other than as a stepchild?

I wonder what part the Society has taken this year regarding the more or less vital legislation which arose in Congress? Our committee was not contacted regarding any action and since no known precedent for action had been set by the Executive Committee, the chairman did not take the responsibility for originating such. It is believed that if future committees be specifically instructed regarding these matters, certainly we in fisheries could accept defeat more gracefully than if we had merely recorded such action without protest in a well worded future Volume of the TRANSACTIONS of our American Fisheries Society.

"HOME-RULE" IN NATIONAL-STATE RELATIONS

RICHARD H. STROUD

I shall discuss some implications of "home rule" as it applies to National-State relations . . . I shall attempt to do so in terms of state responsibilities, real or fancied, from my point of view. The subjects of high dams *vs.* anadromous fish; the multiple-use of municipal water supplies and public access to fishing waters seem to be of considerable importance to the future development of sport fishing opportunities.

The effect of high dams on anadromous fish is of immediate import in the Northwest. It is obvious that each high dam erected on a salmon-

steelhead stream further limits the remaining spawning area. Relocation of spawning runs will help but cannot achieve the impossible. As long as only the northwestern states are concerned, little can be done to slow down the inevitable destruction pending possible discovery of ways to pass salmonids safely and quickly over high dams in both directions. The remaining salmon and steelhead spawning areas in the Columbia drainage —the Snake River and its tributaries—undoubtedly present the finest remaining potential high dam sites. If a moratorium on construction of high dams is to be pushed—an idea proposed by Dr. Arthur D. Hasler—all the states would have to support the move strongly. It might be worth the effort.

In some states large reservoirs may prove beneficial to fishery resources. In other they may prove harmful. In any event, it behooves the states to delve into possible long range plans for river engineering projects and to undertake studies now to establish the present and potential values of the sport fisheries. Such a procedure will permit the states to discharge their moral responsibility and give them an opportunity to help the U. S. Fish and Wildlife Service do its job better through the Office of River Basin Studies in accordance with provisions of the Coordination Act. Weak as this Act may be, its present potential in dealing with federal construction agencies cannot be realized without adequate information.

Multiple use of municipal water supplies is also important. We have long been accustomed to looking for expansion of water area for fishing through the activities of federal construction agencies. Often, however, federal projects such as reservoirs have failed to live up to advance billing, or have produced inferior fisheries, or they have brief life expectancies because of rapid rate of siltation. Many such impoundments have yielded phenomenal early fishing and some have made significant long-range contributions to sport fishing.

Another important potential source of public fishing has too often been overlooked. This is municipal water supplies. Leading communities in a number of scattered states, notably California, Oklahoma, Ohio, New York, and Massachusetts, have shown the fallacy of withholding these waters from angling by sponsoring successful controlled public fishing programs in their water supplies for many years.

The story of multiple use of reservoirs is well told by Dr. Charles Dambach in the August 1956 issue of the OHIO CONSERVATION BULLETIN in an article entitled "A Water Reservoir Has Many Uses." Many states might find it desirable to explore the possibility of establishing controlled public fishing in water supplies. These are often located near large metropolitan areas, where angling recreation is needed. Properly managed they offer a new and untapped source of revenue for tax-burdened municipalities. This argument sometimes helps overcome other objections.

Fishing must be established as a beneficial use of water. What is involved here is recognition of sport fishing as a *primary beneficial use* of water.

This fact needs to be established specifically and clearly in state water laws. It should be noted that at least 18 states are known to have study commissions currently at work on water law recommendations. Adequate water to support angling—our most important and popular outdoor recreational use of leisure time—is a critical problem now. And this problem will become more critical in the near future. Generally speaking, state laws which control water use fail to recognize, as a beneficial use, the utilization of water for fishing and other closely related water-dependent sports. This means that demands for industrial and/or agricultural water may divert virtually at will water supplies needed to maintain important fisheries. Conservationists will have failed to do their jobs if they do not secure appropriate recognition for angling in state water laws.

The problem is not confined to the Western states. The competition for water is stiffening everywhere. It is already past time for conservationists to drive for a place in the legal sun beside those other interests that are fast elbowing the fish and wildlife resources out of the picture.

We must re-orient our thinking. We must develop a new concept of minimum acceptable habitat standards which are broad enough to assure the existence of adequate fish populations to meet the needs of America's many millions of outdoor-minded citizens. Water *quality* standards are only a start in the right direction. New standards for minimum water *quantity* are needed now and will be needed even more in the future.

It appears that the chief responsibility in development of water rights law logically rests with the states. Progressive action is needed on the part of local groups to seek adequate recognition in state water law for sport fishing (and thereby for the fishery resource on which it depends) as a primary beneficial use of water. It is later than many of us think. The time for concerted action is here.

Public access to fishing waters is essential. In my opinion, one of the most important responsibilities of the state fishery units is to provide permanent public access to existing and contemplated fishing waters. Some states are aware of the need and are moving rapidly to safeguard fishing facilities for future generations of U. S. citizens. Curiously, Alaska is perhaps as hard pressed for public access as is Massachusetts! It seems important and timely to ask these questions: Will the hundreds of millions of dollars spent in the last half century on various aspects of fishery management and research have been spent ultimately for the benefit of a relative few thousand riparian landowners? Will we, in fact, have installed the European system of sport fishing for the privileged few through default in this vital matter of providing public access?

The next one or two decades may well give us the answer. The point is, it is not yet too late to do something about it. All that is needed is to set aside a small percentage of the annual state fishery budget to purchase and maintain access sites. Make no mistake, the states cannot avoid this responsibility. I believe that access should be purchased outright in most

cases. Then ownership is perpetual. There is great resistance to this in some quarters on the grounds both of initial cost and annual cost of maintenance. But the choice is clear, the decision cannot be postponed or we may fail in one of our chief responsibilities.

The bugaboos of high initial and annual maintenance costs will not bear close inspection. We have built enormous hatchery systems at far greater cost than access sites may be expected to reach. We have maintained those hatcheries at staggering annual costs, often with relatively poor return to show for it after many continuous years of operation. The annual maintenance of access sites will be a small fraction of that tremendous outlay. Actually, many means of access maintenance suggest themselves and often at little direct cost to the annual budget.

In the final analysis it is the *will* to do the job—to discharge basic responsibilities—that is at test here. If it comes to a choice, access acquisition may well be given the highest priority.

There is need for fundamental research. Undoubtedly on a par with the need for vigorous programs for securing access to fishing waters is the need to enlarge our stockpile of basic knowledge about fish life, aquatic ecology, and fish population dynamics. Forced as the states often are by practical considerations to confine their investigational work to short-term projects, they must look logically to the federal government to undertake much of the needed long-term fundamental research.

So far, Federal research has been good but sharply limited in the sport fishery field—in deference to strong emphasis on commercial fisheries. Later at these meetings, the Director of the U. S. Fish and Wildlife Service will release a report on a national survey of hunting and fishing expenditures during 1955. The amount of money spent on sport fishing far exceeds the retail value of all products of the commercial fishing industry including all added value due to processing and handling at all levels. Obviously research by the federal government on the sport fisheries has been woefully neglected in comparison to its national importance and logically should be developed far beyond the scope of corresponding commercial functions.

The 84th U. S. Congress passed the Fish and Wildlife Act of 1956, now designated as Public Law 1024. Most of you know many of the details. It has received much publicity. I wish to point out, however, that the Secretary of Interior has considerable freedom of administrative action under its provisions.

There is reason to believe that a strong appeal from this organization would fall on sympathetic ears at this time. I recommend, in the dual interest of the general public and of our profession, that we as a body urge the Secretary to establish a Division of Sport Fisheries in the new Bureau of Sport Fisheries and Wildlife. And further, that this Division should at the very least include a new Branch of Sport Fisheries Research in addition to a Branch of Fish Hatcheries.

To provide a nucleus for the proposed research unit, it would seem

appropriate to request the transfer of the entire Section of Inland Fisheries from the old branch of Fishery Biology, together with the research functions of the hatchery branch. We should be realistic and take the long view that the Great Lakes program is more important to future sport fishing than to commercial fishing both to the midwestern area and to the nation as a whole.

Similarily, we should urge that all salmon hatcheries, many of which also raise great numbers of trout, logically belong to Sport Fisheries. The increasingly restricted salmon resources in northwestern U. S. because of construction of high dams, coupled with increasing salmon sport fishing needs and values, should indicate future trends clearly. It does not seem unreasonable to predict that it will require only a decade or so before all salmon resources (other than migrant sockeyes) will be reserved for sport fishing by the northwestern States.[1]

The challenge, the opportunity, and the need are all here now. I believe we should seize professional leadership and urge the Secretary to initiate some such action as I have proposed.

The present federal trend is propitious. It seems to me that favorable action by the Secretary would be a logical extension of the administration's apparent policy of fostering state leadership in fish and wildlife matters. I base this comment on an interesting recent development, an outgrowth of a 1954 Study Commission's recommendation that Service activities be regionalized. Recently the major responsibility for project approval under the Federal Aid to Fish and Wildlife Restoration program (D–J and P–R) has been delegated to the Regions. This should make for closer harmony between the state and federal administators in these key programs. It is also to be hoped that similar sympathy and understanding would attend a concerted demand by the states for an organized and substantial federal program in sport fishery research.

THE BROAD APPROACH NEEDED TO IMPROVE INTER-AGENCY RELATIONS

William H. Thompson

It has been said facetiously that "if it were not for people this old world would be a lot better place to live in." Seriously the same thought was applied to inter-agency relations because it is with people in the agencies first we are mostly concerned. Laws and policies of agencies are usually overshadowed by administrative determinations and personalities.

It is a sign of maturity when a government employee can sit down with representatives of other agencies and seek ways to attain mutually acceptable

[1]Oregon citizens voted overwhelmingly on last November 6 in favor of Initiative No. 7 to outlaw commercial fishing in all coastal streams south of the Columbia River.

programs, recognizing conflicting interests, some of which may not be reconciled, and yet remain impersonally loyal to the laws and policies which define and limit his activities. Until this stage of maturity is reached a government employee can easily defeat the purpose of government rather than aid it.

So far as my experiences indicate, bitterness that develops all too frequently between agencies is often animosity between personalities rather than to real differences between agencies. The absence of a mature viewpoint which we are all more or less guilty is reflected in the following characteristic attitudes.

There seems to be prevalent a feeling that if we could get a law passed to force our viewpoint the problem would be solved. Experience, however, indicates that laws are seldom passed in language to achieve such ends and that when passed they are still subject to interpretation by the people of varying interests, no two of whom can be expected to fully agree on the intent of the law. We must remember too, that laws must satisfy not one but several interests. Another point worthy of consideration is that laws are made by Congressional representatives—people who collectively have had much experience in such matters and are as conscious of their responsibilities as we are of our own. As a good example, it is safe to assume that the Coordination Act (Public Law 732) does not completely satisfy any one interest. Many interests are considered in this legislation and we must be fair and admit that if it succeeded in completely satisfying any single agency it would not be a good law for the public good. Furthermore, it would be shortlived. From this viewpoint it might well be that Public Law 732 is an outstanding piece of legislation because it compromises among various interests. Yet we know there are interests at both extremes—one seeking to put "teeth" in 732 and others seeking to abolish it.

Another common failing among Government employees is the human tendency among us to read between the lines of laws and ignore the intent of the Congress. If Government employees would make a sincere effort to understand and carry out the intent of law it would certainly do much to improve efforts at coordination.

Another common weakness among us is the failure to familiarize ourselves not only within the laws and policies authorizing and limiting our own purpose and existence, but the purpose and existence of the people we are trying to do business with. Too often personnel of another agency will say "Why don't you do this or that." The answer may have been obvious "under the law we can't — and we want to stay out of jail." A person out of Government may have some excuse for demanding unauthorized action on the part of Government, but there is no justification for Government employees hurling such nonesense at each other. It is essential to coordination to know what the other agency is authorized to do.

Another failure contributing to bad agency relations is tendency for us to adopt the narrow view that no agency has a cause as worthwhile as our

own. It is necessary that we accept the evidence of existence and continuance by constant legislative action and that all agencies are legitimate and necessary to the national welfare. There is no other possible grounds for official procedure and we cannot assume the arrogance of allowing our personal evaluation to influence our professional views. So far as we Government employees are concerned, each agency — federal, state and local — does exist and by reason of its legal right, its validity is fully established.

Some of us even lose sight of the purpose of a government agency. The purpose is simple enough; to serve the people in that manner authorized by the people. For example, a fish and wildlife agency cannot be said to be concerned with fish and wildlife alone but rather with the administration and management of those resources for the benefit of people. Similarly the responsibility of the Corps of Engineers is not flood control, but rather provision of flood protection for the people. This may seem superfluous, and self evident but most of us tend to forget a great deal of the time exactly for whom we are working.

It is most interesting to occupy a position as biologist in an engineering agency. In such a position you can imagine how irritating would be an attempt to discuss a problem with a co-worker with no biological background but perhaps most highly qualified in hydrology who assumes he knows as much about one profession as the other. Similarly experience recalls a biologist with no technical knowledge of engineering who bitterly criticised a dam as being needless expense because as he said, "All that water could have been discharged through one hole instead of four." This assumption of technical expertness is something that all professionals are confronted with from writers, speakers and others, but the same conflict should not exist among Government employees. This assumed expertness in non-qualified fields is a real source of animosity and a hindrance in the co-ordination of mutual interests.

Good relations among agencies are made by individuals who are well informed and have the desire and ability to think broadly and objectively.

EDITORIAL BOARD

Kiyoshi G. Fukano

In March the Editor informed the Executive Committee of the American Fisheries Society that he was resigning from the task, after completion of Volume 85.

I extend my thanks to the Associate Editors who have spent their time and effort in the publication of the Transactions during my Editorship.

I make the same recommendations that Dr. Lloyd L. Smith made in his 1952 Report of the Editorial Board, namely, that the Society either hire a full-time paid Editor, or pay a Secretary or Assistant to the Editor for some of the detail work.

COMMITTEE ON HYDROBIOLOGY AND FISH CULTURE

GERALD P. COOPER

This year, the Committee on Hydrobiology and Fish Culture has not prepared a report covering the general field. Rather, we have assisted the program chairman in arranging for a series of papers, (contributions from original research) on two important aspects of hydrobiology and fish culture, to be presented during the time allotted for the Committee report. By this action we are following the precedent set at last year's meeting at Augusta, Georgia; and our action is in agreement in principle with the suggestion made by Campbell (TRANSACTIONS, Vol. 84, p. 356) that annual reports by this Committee be more restricted as to coverage of subjects.

The two aspects of the field of hydrobiology and fish culture, represented by the present series of papers, are fundamental problems in lake biology and modern trends in hatchery trout feeding (especially the use of pelleted dry rations). Our attempts to obtain good geographical coverage as to localities of the studies have been at least partially successful. The papers in question and which are included in the present Volume of the TRANSACTIONS are those of T. F. Waters, E. F. Grassl, and R. I. Stevens and J. Truog.

COMMITTEE ON COMMERCIAL FISHERIES

LESLIE W. SCATTERGOOD

This report of the Commercial Fisheries Committee has a two-fold purpose. First, as in past years, it presents information on the production, trends and developments of the more important North American commercial fisheries for the year 1955. Second, it offers a few thoughts and questions concerning the future of the fisheries and the need and possibilities for increased production in the decades ahead.

The members of this committee have assisted in providing information on the fisheries with which they were most familiar, and Mr. W. C. MacKenzie, Director of the Market and Economics Service of the Canadian Department of Fisheries, kindly furnished a review of the 1955 fisheries of his country. Their help is sincerely acknowledged.

COMMERCIAL FISHERIES OF UNITED STATES AND ALASKA

The commercial fishermen of the United States and Alaska caught in 1955 an estimated 4.6 billion pounds of fish and shellfish valued at 325 million dollars.[1] Compared with the previous year, this was a drop of about

[1]The statistical information concerning the 1955 fisheries has not yet been completely compiled for all species. No data are now available for fresh-water fisheries. Estimates are used for the total United States figures; the data on the landings of the principal species are available so that the possible error in the estimated total is low.

45 million pounds and 35 million dollars. This difference is the net result of some gains and some losses, rather than a uniform decrease throughout the industry.

On the Pacific coast, including Alaska, the principal production is of tuna, salmon, sardines, herring, and halibut. The tuna industry continued to suffer severe setbacks during 1955, and the catch fell 18 percent from the previous year. Increased imports of canned and frozen tuna, wage disagreements; and large carry-over stocks marked the West coast tuna industry in 1955, and the catch declined to 264 million pounds. The Pacific salmon fishery dropped alarmingly, and the catch of these species in the United States and Alaska fell to about 286 million pounds, which resulted in the smallest pack of canned salmon since 1906 when the industry was young. Pacific sardines, once the object of a tremendous fishery that captured annually up to 1.5 billion pounds, yielded 143 million pounds, which represented only a slight improvement over the 1954 catch. Factors tending to reduce the production of this species were the continuing scarcity of the fish and delays in opening the season caused by strikes of cannery workers. Had fishing started earlier, the catch would probably have been slightly higher. Alaska herring catches were 63 million pounds, which was almost twice that of 1954, but still below what is considered as a good year. Pacific halibut landings declined from the previous year, and a big factor contributing to this drop was the poor weather during the final week of the legal season. The catch of 59 million pounds, however, was still above the average for the past four decades. Jack mackerel landings doubled in California, but the catch of 35 million pounds in 1955 was only one-quarter of that in the peak year of 1952. Pacific mackerel production continued to decline, and 21 million pounds were caught.

On the Atlantic coast, including the Gulf states, the most important feature was the continued increase of the menhaden fishery. The 1955 catch was 1.8 billion pounds, thus exceeding the previous year's catch by 50 million pounds and establishing a new production record for a United States species of fish. Another great fishery is for shrimp whose catch was about 250 million pounds, representing a decrease of about 15 million pounds from the 1954 total. This decline was attributed partially to inclement weather conditions in the major producting areas. Complete data are not now available for the trash or "industrial" fishery that captures a variety of low-priced species on all coasts of the United States for reduction or animal food, but there was undoubtedly an increase; for example, the fishery for trash fish, exclusive of menhaden, in New England increased 13 millions to a total of 127 million pounds. In contrast, landings of most of the principal species of groundfish and ocean perch (redfish or rose fish), which support the New England fillet industry, dropped markedly in 1955. Haddock fell from 155 million pounds to 136 million pounds, and the total cod catch of 35 million pounds represented a one

million-pound decline. Ocean perch receipts slipped from a production of 181 million pounds in 1954 to 157 million pounds in 1955 as the fishermen continued to seek more distant and profitable grounds. Of the other important Atlantic fisheries, whiting catches rose 20 million pounds to a total of 114 million pounds, and pollock were up four million for a total of 24 million pounds. It is of interest to note that landings of ocean perch and whiting, whose combined 1955 totals were almost 150 thousand tons, are about 30 times greater than those of 25 years ago, when both species were largely ignored. The production of lobsters and sea scallops was near record highs. Maine herring catches declined 24 million pounds from the previous year, and this was largely caused by a shortage of the immature fish that are used as sardines. The fish stick industry continued to expand, and a new record of 65 million pounds was established. This was an increase of 31 percent over 1954. Both domestic and imported groundfish are used as fish sticks.

Imports and exports are important features of the United States fishery economy. Tuna and groundfish imports are of particular interest to the domestic industry. Frozen tuna imports increased to 145 million pounds and canned tuna in brine to 35 million pounds, a total gain of about 26 million pounds. The tuna imports were mainly from Japan and Peru and competed with both domestic fishermen and canners. Imports of groundfish, including those from cod, haddock, hake, pollock, cusk and ocean perch, declined nine million pounds from the previous year and totaled 129 million pounds. Canada supplied about three-quarters of this amount; Iceland, Norway, Denmark, and West Germany were also important suppliers. Imports of shellfish continued to increase, as fisheries for these crustaceans were further developed in other countries. Frozen shrimp imports, principally from Mexico, Panama, and Ecuador, increased 13 million pounds to a total of 54 million pounds in 1955. Frozen lobster and crawfish imports rose three million pounds to the 45-million pound total in 1955. Canada supplied about half of these imports, with the Union of South Africa, Australia, Cuba, and New Zealand contributing most of the remainder.

In view of the American Fisheries Society's interest in fish culture, it is appropriate to discuss trout farming, a commercial fishery activity that is not particularly well known. Mr. Charles R. Foster, a member of this committee, is responsible for the information that is given here. There are estimated to be between 500 and 600 privately owned trout farms in the United States, and their 1955 output is estimated at four million pounds of fish. About half of this total is sold as live fish to state agencies for stocking public waters, or to individuals for planting privately owned waters. The other half is marketed as dressed fish for domestic consumption and competes in the United States market with imports of fresh and frozen trouts, principally from Canada, Denmark, and Japan. Trout imports totaled over four million pounds in 1955.

United States fishery exports are primarily inedible fish oil and canned fish, including sardines, salmon, squid and mackerel. The inedible fish oil amounted to 142 million pounds, only about two million more than the previous year. Of this amount, the Netherlands took more than half and Canada and West Germany together imported a little less than one-third. The Philippine Republic purchased about three-quarters of the canned sardines, not in oil, but in tomato or mustard sauces, that were exported. Other large buyers of the 42 million pounds of these canned sardines were Cuba, Belgium, and Ecuador. These 1955 exports greatly exceed the previous year's total of 16 million pounds. Canned salmon exports also increased over 1954, for the shipments in 1955 were ten million pounds and in 1954 about seven million. The United Kingdom took almost half the 1955 exports, and Canada about one-third. Another important canned product is canned squid, and exports of this item more than doubled in 1955; of the 15 million pounds shipped from the United States in 1955, about 85 percent went to the Philippine Republic.

The most important piece of fisheries legislation to be enacted during recent years was the Saltonstall-Kennedy Act of July 1, 1954. This Act made available to the United States Department of Interior about $3,000,000 annually for a period of three years to "promote the free flow of domestically produced fishery products in commerce by conducting a fishery educational service and fishery, technological, biological and related research programs . . . and to develop increased markets for fishery products of domestic origin and to conduct any biological, technological or other research pertaining to American fisheries."

The Fish and Wildlife Service is the primary research agency for the implementation of the Act, and, consequently, a great expansion of activities and personnel has resulted. The Department of the Interior has adopted the policy that qualified research agencies outside the Fish and Wildlife Service should be given the opportunity, wherever possible, to broaden their own fishery research potentialities by being offered contracts to conduct needed studies in their particular fields. This policy has limited the need for an increase in the Fish and Wildlife Service staff to those projects it is best qualified to study, and it permits the Service to devote its major efforts to the particular fields in which a centralized research agency can operate most effectively. In addition, this policy has placed most problems in the hands of those people best able to solve them either by reason of experienced staff, specialized facilities, or extensive regional knowledge of the subjects. In many cases, it is stimulating local fishery research centers to such a degree that the industry in the not-too-distant future will be able to call upon a much wider choice of capable consultants in many fishery problems. In carrying out this policy, the Department let about 60 contracts in every section of the country for over 40 percent of the funds available for the fiscal year 1955. Contracts were given to 30 universities, colleges, and public institutions, and 13 commercial and in-

dependent scientific research organizations. The Department intends to continue this practice.

Prior to the Saltonstall-Kennedy Act, the Fish and Wildlife Service had been conducting research on the principal commercial fishery problems, both biological and technological. The Act has enabled these main problems to be pursued more vigorously and has also permitted the study of new problems. The biology of the most important commercial species is now being studied intensively, and a great deal of effort is being spent on the exploration, development, and utilization of the fishery resources.

Commercial Fisheries of Canada

The marine fisheries of Canada yielded in 1955 a total catch of 1.7 billion pounds valued at 75 million dollars. Compared to 1954, this was a decrease of 200 million pounds and eight million dollars. Information on the fresh-water fisheries is not yet available.

In 1955 production of the Pacific area's principal species, salmon, halibut, and herring, fell considerably below the previous year's levels as a result of various circumstances. Catches of sockeye salmon were disappointingly low, as were those of the chum salmon. A record pack of pink salmon was a somewhat compensating factor. Total salmon landings were 50 million pounds less than in 1954, and the total landings were only 129 million pounds in 1955. Catches of herring were some 55 million pounds lower than in the previous year, the decreased production being the result of two principal factors. First, the 1954-55 winter herring season ended in February, a month earlier than usual, when new bodies of fish failed to appear; and, second, there was a price dispute between fishermen and reduction plant operators which discouraged summer fishing and delayed the 1955-56 winter season. The 1955 herring catch was 305 million pounds, representing a decrease of 56 millions. The 1955 halibut fishery produced 20 million pounds, which is five million less than in 1954.

The Atlantic coast fisheries yielded 1.3 billion pounds in 1955, about 66 millions less than in 1954. The catch was, however, about the same in weight and value as that of 1953, which may be considered average year. A large decline was that of the cod fishery, which landed about 97 million pounds less than in 1954. This decrease was due almost entirely to the disappointing trap fishery in Newfoundland. The most valuable species is the lobster, whose 1955 catch of 49 millions was the largest since 1932 and had a record value.

Production of fresh and frozen groundfish increased in 1955, and this increase was associated with a greater diversion of cod and haddock to production of frozen fillet blocks for the expanding fish stick industry in the United States. Haddock landings rose significantly in Nova Scotia and Newfoundland, and the total catch was 134 million pounds, an increase of 16 million over 1954. Ocean perch declined about ten percent to 43 million pounds, and mackerel dropped at approximately the same

rate to 27 million pounds. The yields of pollock, hake, and cusk increased four millions to 57 million pounds, and flat fish landings rose about 30 million to 83 million pounds. The herring fishery was about ten million pounds greater than in 1955, but the catch of small herring in New Brunswick was poor, causing local shortages of bait and a decreased sardine pack.

Canada consumes only about one-third of its fishery products; the other two-thirds are exported, principally to the United States, which received about 70 percent of the Canadian exports. Frozen groundfish fillets, live lobster, herring oil and meal, salt cod, and cured herring are the principal exports to the United States. Exports of salt cod from both Newfoundland and the mainland compares favorably with those of 1954, with Caribbean markets showing particular strength.

Future of Commercial Fisheries

According to the estimates of the demographers, the world population is increasing at such a rate that in a century the number of people will be at least twice the present 2.6 billion. It is even possible that the population in the year 2050 may reach 10 or even 15 billion. A less than two-fold increase could result only from a catastrophe.

North America now has ample food for its own needs, but most of the world has difficulty in providing sustenance for its growing population. It is generally acknowledged that more than one-half of the present world population is subsisting on a near starvation diet and another one-fourth is undernourished. Technical assistance programs of the United Nations, United States, British Commonwealth, Norway, and other groups have been aimed at reducing this hunger, but the task is not an easy one, because the dietary deficiencies are most acute in the underdeveloped countries, which are often incapable of quickly taking advantage of modern ideas and techniques. Progress is being made, however, and food production has increased wherever technical assistance has been given. Unfortunately, it has not been possible to increase the food production much more rapidly than the population increases.

A recent study of the world's food problems has been made by the California Institute of Technology, and from this research it is possible to understand the nature of the food shortage. It seems that there is no technological reason why this shortage exists. There is not enough food, because we are not utilizing the potential productivity of the land and sea from which all our food comes directly or indirectly from plants. A much greater population could be fed adequately if changes were brought about in our methods of food production.

In the field of world agriculture, the following changes are necessary. First, humans must consume directly greater proportions of plant food, and decrease the amounts fed to animals; second, plants must be developed that will provide greater numbers of calories per unit area of land; third,

the tremendous wastage of food through spoilage or animal depredations must be checked; and, fourth, as much land as possible must be made arable and cultivated at a maxiumum intensity. These improvements will first be made by the more developed countries and gradually adopted by the under-developed countries upon the urging of the former.

The general methods that may be applied to produce an increased supply of food from the waters are somewhat similar to those mentioned for agriculture. Knowledge of our fresh-water and marine resources is, however, not as highly developed as that of agriculture, but with increasing research we undoubtedly will better understand the complex of factors that control the nature and types of productivity in the waters. In certain types of fresh-water fish cultivation, we are already approaching the efficiency of agricultural methods.

Rather than discuss possible future trends in the yields of human food from the waters of the entire world, this committee has decided to restrict itself to North America. Observations made on the fisheries of the United States and Canada are also applicable more or less to the fisheries of other countries.

As is the case with agriculture, it would be most efficient to utilize marine plants directly as food. In North America, we are already consuming several types of marine algae, among which are the large brown kelps that yield algin, and two red algae, known as Irish moss and dulse. There are tremendous potentialities for increased production of these and other sea-weeds such as the brown rockweeds that cover much of the intertidal zones in the northern waters. These seaweeds are rich in vitamins, but unfortunately the carbohydrates that they contain, although of considerable value in industry, are not readily digestible by humans. A considerable amount of research has recently been aimed towards culturing fresh-water algae as food, but the commercial possibilities of such endeavors are as yet unknown, although they appear to be promising.

To obtain large quantities of food from the waters we must turn to the animal life which includes zooplankton, various invertebrates, and fishes. A method of economically harvesting plankton animals has not yet been devised. Many of the larger invertebrates, such as certain species of bivalve mollusks and decapod crustaceans, are being fished intensively, but there are large untapped sources of smaller, less conspicuous invertebrates that could be used for food, for example the many species of gastropods, the univalve and smaller bivalve mollusks, echinoderms, and a number of species of crabs not now eaten. Most of our increased food production, however, must be obtained from the fishes, many of which function efficiently to convert the small plants and animals into protein that is readily available to humans.

One method by which the production of fish can be increased is through the greater utilization of some of the species that are not now harvested at an optimum rate. To determine the optimum rate of exploitation of a

species is a problem that only fishery biologists, in close cooperation with the fishery industry, can solve through intensive research over a considerable period of years. This is the goal of almost all biological investigations in the fisheries.

Another possibility for greater production is by means of thorough surveys of the areas not now fished commercially. Such endeavors are exploratory in nature and must be carried on until all habitats in which fish or other edible forms might dwell have been searched regularly. Deep-water regions off the coasts, mid-water areas, and seldom fished banks must be systematically investigated throughout the Northern Hemisphere. This will mean that new types of fishing gear will need to be devised, and perhaps completely revolutionary ideas will result in great changes in many of our fisheries.

Biological control of undesirable species that act as either predators or competitors with the valuable species offers another means by which the food supply may be augmented. For example, at the present time we need to control the lamprey that attacks Great Lakes fishes and the green crab that has been largely responsible for the decline in the New England soft clam population. In fresh-water, control of the fish fauna is now commonly practiced through the use of chemical killers. Ponds, lakes, and streams may be stocked with edible varieties of fish after the undesirable species have been eliminated.

One of the important fish-cultural developments during the past few decades has been the use of farm ponds and reservoirs for raising fresh-water fishes. With greater knowledge of how to manage such water enclosures, and what species are most suitable, a valuable addition can be made to the countries' food supplies. Fish-farming is of tremendous importance in the Orient and parts of Europe, and we can anticipate that, if necessary, we will be able to increase greatly our harvests in North American fresh waters.

The prevention of spoilage is another problem that must be investigated, if the fullest use of our marine and fresh-water resources is to be achieved. In the primary operations of the great fisheries, spoilage means more a loss of monetary value than of food value, for fish that are unsuitable for human consumption are diverted to reduction plants to be manufactured into fish solubles or meal. At the retail level, however, fish spoilage may mean a complete loss of the product, and the incidence of the rejection of decomposed fish is dependent upon the conditions which prevailed from the time the fish was caught until it reached the retailer and ultimately the consumer. Improvement in the quality of fish products is the concern of the technologists, and their increased research in the future will undoubtedly reduce the amount of fish that is entirely wasted because of spoilage.

In the future, we must consider whether available food supplies are great enough to allow us to continue the large scale feeding of livestock

and poultry. Great quantities of grains, fish meal and fish solubles are fed to those animals which we in turn consume. The return of calories from the animals may be only about ten percent of the food value from the feed if it were fed directly to humans. Ultimately, we may have to eat increasing amounts of the fish meal or solubles or the fish from which these products were made. Fish meal, when specially prepared, is a palatable and valuable addition to human diets and is already being used as such in a few countries. Menhaden, herring, and sardines, the great favorites of reduction plants, could be processed in increasing quantities as human food, and trash fish now made into by-products or fed to fur animals could undoubtedy be similarly used.

If the economy of the United States and Canada continues at a level that is so much greater than most of the world, we may not have to worry about our own food supplies, but there is no doubt that our responsibilities towards other, not so fortunate, nations must force us to consider seriously the future of the world's food supplies. Before the end of the next hundred years, historians may regard this present time as one of almost incredible abundance, and the conditions that have produced food surpluses and needs for crop reductions will be considered as historical curiosities.

COMMITTEE ON NAMES OF FISHES

REEVE M. BAILEY

This Society's first (and thus far only) official list of names of fishes of the United States and Canada, was published in 1948, first as a Special Publication and then in the TRANSACTIONS. The common and scientific names of 570 well-known species were included on that list. In the interval since its appearance, a limited number of corrections, changes, and additions to the list have been made. These may be found in the committee's reports in the TRANSACTIONS. During the past eight years, the taxonomy and nomenclature of fishes has not remained static. A few kinds included on the original list have been demonstrated to be synonyms of other species on the list. Many species then omitted have for one reason or another become of sufficient importance now to merit inclusion on the list. The scientific names of many additional species have been altered. Emended common names, although on record, are often overlooked by those using the published list. It becomes apparent, therefore, that the need for a revised list is increasing. Through sales of the first list the Society has already recovered the financial outlay for printing, and only a few hundred of an original run of four thousand remain on hand.

Early this summer, on the occasion of another meeting, it was possible to establish a quorum of this committee. At that time, we decided to commence active preparation of a revised list. Many of the difficulties

experienced in the preparation of the first list revolved around the lack of an adequate set of guiding criteria to be employed in the selection of names. This deficiency has now been met through the preparation of the set of principles which appeared in Volume 84 of the TRANSACTIONS. That instrument will provide a working basis for expansion of the list.

The target date 1958 is set for the completion of the second edition. It is anticipated that the new list will include the material covered in the first list, the statement of principles, and a substantially larger number of species. Because most of the present members of the committee are specialists on freshwater fishes, particular effort will be directed to the elaboration of the coverage of freshwater fishes in this edition. In addition, we plan a number of changes in format. We expect to add scientific and common names of families, to insert the names of authors of scientific names, and delete the plan of numbering the species in the list. As in the earlier edition, there will be indication for each species as to whether it is Atlantic, Pacific, or freshwater in distribution. Scientific names will be indexed both under genus and species. Accepted common names will be indexed alphabetically. In addition, there will be included an expanded list of those common names which have been or are in active use, or appear commonly in the literature, but which are not accepted as official. For each, the equivalent accepted name will be shown.

This can be no solo effort. Although the committee will do the bulk of the work, the advice of many will be sought. The operational procedure is for each committee member to assume responsibility for the preparation of preliminary lists for certain families of fishes. These will then be circulated to other committee members, and to specialists not on the committee. Decisions will be made only after a thorough canvass of the possibilities and a weighing of pros and cons among names in contention. In this undertaking we enlist your cooperation and advice. If you have been using the list, let us hear your criticisms or ideas for improvement; if you don't, how can we make it an effective tool?

We expect also to attempt to mediate differences between entries on our list and those of other agencies which are independently striving toward the same end—stability and uniformity in common names.

COMMITTEE ON WATER POLLUTION

GEORGE E. BURDICK

In 1955, the first year after becoming a standing committee, the Committee on Water Pollution embarked on a three year program designed to establish an inventory of the organizations and agencies involved in the control of, or research on pollution affecting aquatic life. It was decided to include a bibliography of pertinent publications of the organizations conducting research in order to increase the value of the inventory and

add to its use by members of this Society.

The information and material obtained in the second year of this project, plus that received too late for inclusion last year, forms the basis for this report. A part of the material submitted for one section of the United States has been omitted in order that it might be carried in the final report as initially planned. It was deemed advisable to publish the material in installments, one in each of the three years so that future committees can maintain a current inventory if they think this plan best serves the interests of the Society.

The committee wishes to express their thanks and appreciation to all who have cooperated by filling out and returning the forms used in this survey. We find, however, that we are falling short of our goal of complete coverage, due to the failure of some to complete and return the requested information. It is only through exhaustive coverage that an inventory of this nature can be of maximum value and use. For this reason, we request your assistance and cooperation in replying to any inquiry which we may make of you in the future, whether or not you believe the information you can supply will add appreciably to the effectiveness of the inventory.

It is an obvious impossibility to present orally, with the time provided, all the data which have been submitted and on which some of you may have different points of view. Even as a written report these data are so voluminous that the report would be too long for publication as a committee report in the TRANSACTIONS. A mimeographed summary has therefore been prepared to supplement this report, as was done in 1955, and is available to those desiring this information. The remainder of my time will be devoted to extracts from the replies which may be of general interest.

Of the 21 control agencies covered in this report, 13 indicate no change in staff during the past three years, five report an increase, while three report an involuntary decrease, due to an inability to recruit at their permitted salary scale.

Twenty-eight returns were received from organizations believed to be engaged in research on the effect of pollution on aquatic life, or on treatment processes likely to reduce the effect of pollution on the aquatic community. Ten report an increase in effort; three show no change; one, a decrease; five fail to indicate the time accorded these activities and nine engage directly in no research on the effect of pollution on aquatic life. Survey work, ecological studies, and investigations incidental to the enforcement of pollution laws appear to have been included as research. Although not all such studies may be justifiably included, no correction has been attempted and the time figures are assumed to be too high. Distributed among 14 agencies, the effort varies from 15/100 to 14 man-years per year, for a total of 38.4 man-years. Twenty-six of these research man-years are applied in research on radioactive wastes, 3.1 are based

on thesis and contract work at educational institutions and must be considered as temporary, four are in the Taft Engineering Center of the U. S. Public Health Service, leaving 5.3 man-years to be distributed among the remaining seven agencies.

Some advancement in the past 3 years has been reported in the field of methods of treatment or control of pollution which might affect fish life. In Mississippi, the State Oil and Gas Board must now require all salt water to be discharged to sub-surface strata. Louisiana State University reports that impoundment now appears a practicable method for elimination of pollution from the sugar industry, and that the National Council for Stream Improvement at that institution has developed an activated sludge process for kraft mill wastes which has now been in operation at the West Virginia Pulp and Paper Company for about a year.

Research in the treatment of phenolic wastes is being conducted at the University of Oklahoma under an air force contract.

An interesting cooperative project involving the U. S. Fish and Wildlife Service, the U. S. Public Health Service and the states of Massachusetts and Connecticut is underway on the Connecticut River. Briefly, a pre-construction study of conditions in the river at various water-stages will be used as the basis for a projection to determine the probable effect on the stream of the construction and operation of a power dam. It is hoped that this study will provide information whereby the flow water necessary for satisfactory conditions for fish life can be determined. It may also serve as a model for the evaluation of similar construction on other streams.

Trash, old bedsprings, auto tires, tin cans, bottles and other rejects of the times litter the bed banks of streams in country as well as urban areas. Far too frequently, the village dump is located on the bank of a stream where high water can wash part of the accumulation to the stream each spring. Many water pollution control laws legally define pollution as the impairment of any recognized use, so, to the extent that use for fishing is impaired, such conditions can be considered to be pollution. Attempts to prohibit the disposal of such materials in streams by local ordinance or state law have been only partially successful. The right to litter banks often appears to have been considered a vested property right. It remained for the 1954 Manitoba water pollution control law to assert the right to regulate the use of the banks in relation to control over waters.

This law states "No person shall leave, deposit, or throw, or cause to be left, deposited, or thrown, any manure, night soil, decayed or decaying matter, the carcass or offal of any animal or fish, or part thereof, lime, chemical substance, drugs, poisonous matter, garbage, refuse, cans, bottles, rubbish, or any other filthy or impure matter of whatsoever kind, within two chains of the normal highwater mark of any body of water, or into the waters of, or upon the ice of, any body of water."

If enforced and enforceable, this law will assure the Province of Manitoba an unspoiled water vacationland, a haven for those with a distinct aversion

to removing trout from the shelter of a bag of garbage or an old auto tire, or have felt their blood pressure rise as the result of a cut boot or a leader frayed on the sharp edges of a defunct garbage can.

Progress in pollution control is made possible by continued public demand. In the record of laws passed, or modified, may be read the story of continued or relaxed public interest. Within the segment of the states and provinces covered by this report, during the past three years, Manitoba, British Columbia and Utah have passed new pollution control laws, while Quebec has set up a committee to study the measures necessary to prevent and control pollution. Reported amendments have been increasingly restrictive, for example Alabama has removed previously-listed industrial streams and restricted the power of the Board to name others. Mississippi now requires all salt water to be disposed of in subsurface strata. Texas has given the Railroad Commission power to regulate the disposal of oil field brines. The Massachusetts Health Department has been given the power to close shellfish areas immediately in the event of emergency involving pollution. The fines for continued pollution have been increased in Saskatchewan.

This part of the story can be considered good. However, in 1954, the Utah Water Pollution Control Board adopted standards for A and B waters, which, while recognizing the use of such waters for fish and fish propagation, pinned their criteria of pollution to the U. S. Drinking Water and Irrigation Water Standards. There are at present no generally accepted criteria, similar to the U. S. Drinking Water Standards which may be applied for protection of fish survival and reproduction. In their absence, the blame for the passage of laws with water quality too low for the protection of fish life, must rest primarily on those with specialized knowledge as to what restrictions and standards are necessary.

There is little chance of producing, within a reasonable period of time, universally accepted water quality standards for fishes covering all known or potentially toxic and injurious materials. With properly designed and coordinated research, it seems probable that generally recognized and acceptable standards, parallelling those of the U. S. Drinking Water tables can be formulated in a relatively short time and be available for use when fish must be protected. Such criteria are urgently needed.

MEMBERSHIP COMMITTEE

Clarence F. Pautzke

In drawing up the plans for increasing our membership, it was the general consensus of opinion of the Membership Committee that the persons engaged in the field of fisheries interest were not being adquately contacted. Therefore, a series of categories was set up in order to encompass as many of these individuals as possible who were interested in fish. Key men were chosen who would be in contact with these different categories.

We have those individuals employed by the federal government consisting of administrators, research workers, and those in the propagation branches. This applies also to the states and provinces.

Then, under the heading of private enterprise, there are a great number of fisheries researchers working in conjunction with power companies and other commercial organizations and also those conducting their own personal consulting work. We have the commercial fish farmers, an ever growing group of men who are interested in the commercial rearing and marketing of fish.

Another group consists of the sports clubs, many of which are dedicated to the interests of fishing. Through their efforts great pressure is often applied to conservation agencies, yet many of these clubs are ill-informed on fisheries matters.

A large untouched field is the fishing equipment manufacturing companies.

The Membership Committee set out to contact these different agencies that are interested in fisheries activities. I cannot say too much about the fine job done by the members of this Committee. Although already overburdened with activities required by their positions, they took the time to acquaint the fisheries workers of their areas with the objectives of the American Fisheries Society.

REPORT OF SPECIAL COMMITTEES

COMMITTEE ON EMPLOYMENT

L. P. Voight

A resolution passed at the American Fisheries Society annual meeting in 1950 called for the establishment of a committee to survey the employment situation, to prepare a guide to professional standards for use by employing and training agencies, and to publish newsletter summaries of the employment picture at intervals for all members. The resolution also favored the establishment of this group as a permanent standing committee through constitutional change.

As a result of this resolution, a temporary committee was set up and this group made reports to the 1951 and 1952 meetings—after which the committee evidently was discontinued. Their first progress report made some general observations, and the second contained several recommendations including the following: (1) that a listing of fishery personnel training curricula at the various schools be prepared and published, with a reprint of it to be sent to prospective students in this field as well as to vocational guidance personnel; (2) that fisheries work be encouraged as a profession equal to others, such as engineering; and (3) that the committee should not try to set up an employment service or agency. These recommendations are still valid today and have much merit within their limits. Experience seems to

show that this is a difficult service for a committee to perform well.

This problem of proper placement of a professionally trained individual is common to all professional groups. Its successful solution is important to both employer and employe. In the business world some corporations would gladly pay $1,000 to assure obtaining the right research man or technician for a specific job. In fact, they often spend a considerable amount to secure and train a man for one position. In some other professions the employers enter a race with others each year at the colleges and universities, offering high salaries and special dispensations if the graduate will come to work for them. Even some public agencies have been forced into this contest in order to secure personnel. Obviously, the placement problem is not difficult for the employe in such situations where people with technical training are in such great demand.

For this reason, the American Society of Professional Engineers has no placement service and the National Society of Professional Engineers only lists openings and available employes in their national magazine. The Society of American Foresters solves the problem by publishing listings of positions wanted and available in the JOURNAL OF FORESTRY so that employer and employe can enter into negotiations. This is a common practice in many organizations which have periodical publications or news sheets. In the case of librarians, there is a privately operated Library Placement Exchange which collects and publishes job information in the library field and charges for the publication, giving subscribers a chance to list their needs. Medical Societies and Bar Associations usually register needs in their fields with their secretaries, and some other associations have a special committee to handle this activity.

In recent years one of the common procedures used to solve this problem is the placement service operated in connection with the organization's annual meeting. The U. S. Employment Service has been furnishing free of charge a complete placement service at the meetings of such large organizations as the National Conference of Social Work and the American Economic Association. Also, for smaller meetings such as ours the free assistance of the Employment Service in the state where the meeting is held has been used successfully by such groups as the American Sociological Society, the Pacific Regional Conference of Child Welfare and other groups.

In the wildlife field, the Wildlife Society has operated a placement service at the recent North American Wildlife Conferences and also continues this referral service throughout the year through their Committee on Employment. At the 20th North American Wildlife Conference job openings for 33 fishery biologists were listed and well over 100 applications for wildlife positions were on their register. However, the committee's published report on July, 1955, states that they have no report system to determine which positions are filled or applicants hired, and no evaluation of the program's value was then available.

Attention must be called to the importance of some standardization of

employee position classification into key classes by conservation agencies. This is necessary for an understanding of professional standards which must be met in specific types of jobs to help bring the applicant and potential employer together without too much difficulty. This problem was discussed in some detail in the report of the Committee on Professional Standards to the 1954 Convention of the International Association of Game, Fish and Conservation Commissioners held at Seattle. Many of the recommendations in that report should also be considered by the American Fisheries Society in any program undertaken in this field.

It is the committee's belief that the American Fisheries Society should not attempt to operate a complete placement service throughout the year because that type of operation requires the publication of a periodic news bulletin or similar periodical and also additional staff personnel. The cost could be prohibitive and the results questionable. However, some assistance could be given to potential employers and members by two practices which the Society might institute without excessive cost:

1.—Invite all members and new applicants for membership to file a statement of their education, experience, publications, and other factual data with the Secretary and offer information from this data file to employers searching for qualified personnel. It would be the duty of members to report significant changes, and a new questionnaire could be distributed every five years.

2.—Extend each entry in the annual membership list in the TRANSACTIONS by an additional line or two to make it more of a directory containing information as to the individuals educational attainments, job classification or specific fields, age, and other pertinent data in abbreviated form. This would be based on a postcard questionnaire and such data would be included in the membership list only if it was supplied by a deadline date.

In addition to these suggestions, the committee makes the following three recommendations:

1.—That the American Fisheries Society's Executive Committee consider the possible use of the free professional placement assistance of the local State Employment Service in connection with their 87th Annual Meeting in 1957. If used on an experimental basis, this would call for the shipment of job orders and job applications to the local Employment Service office before the meeting so they can be processed and matched for interviews to be held as much as possible during the convention. It would require contact announcements to potential employers and Society members as well as cooperative planning with the local Employment Service. This experiment should then be evaluated to see how well it succeeded in matching employes with available employment opportunities.

2.—That if such experimental convention placement program proved successful, the American Fisheries Society encourage its membership and potential employers to use the resources of the State Employment Service's professional placement division throughout the year. This is a tax-supported

program with almost 2,000 stations throughout the country. A number of the larger cities have special programs for placing professional personnel. They furnish without cost a service of applicant employment record preparation and referral to all states. Similar arrangements are doubtless available in Canada.

3.—That this committee, or a similar committee, continue to operate primarily to investigate the possibility of developing some sort of coordinated or cooperative program with other related organizations which are trying to solve this same problem. In addition to the activities of the Wildlife Society, other interested groups may include the American Society of Ichthyologists and Herpetologists, American Society of Limnology and Oceanography, American Society of Mammalogists, and the International Association of Game, Fish and Conservation Commissioners. There are also a number of others which could be mentioned.

4.—Include a list of "positions open" supplied by prospective employers and "positions wanted' by members with each newsletter sent out by the President and Secretary. It may be possible that some organization such as the Sport Fishing Institute, the Wildlife Management Institute or the Conservation Foundation would consider this operation of a full-time placement service to take care of this entire field and would also assist in setting up uniform job classification standards. Each participating organization might contribute funds proportionately toward this program if necessary. The results certainly would be more efficient and successful than when handled sporadically or by non-paid committees or other Society officers. Also, this procedure could be a long step forward toward the establishment of professional recognition for workers in these fields through the establishment of reliable personnel standards upon which employer and applicant could depend in their negotiations.

At the last moment, when the final draft of this report was already prepared and approved by the committee members, the Sport Fishing Institute sent out a request for information on vacancies in fishery positions throughout the country. A telephone contact with Richard H. Stroud, their Executive Vice-President, revealed the fact that the Sport Fishing Insitute would be willing to expand their activities in this field to include fishery position and applicant data for all types of agencies and institutions in both Canada and the United States on a semi-annual basis. In fact, they plan an additional man on their staff who could be given this work as part of his regular assignment. This new development certainly deserves full consideration by the Society's membership and the Executive Committee. It may be the best possible solution and could be augmented with some of this committee's other suggestions. As the Sport Fishing Institute evidently would also attempt to bring together the employer and applicant in a planned interview session in connection with the meetings of both the American Fisheries Society and the North American Wildlife Conference, cooperative interview planning through local Employment Service channels may be unnecessary.

Your committee would be willing to assist the officers in their planning to carry out these suggestions and recommendations and welcomes any constructive criticism which may help determine the best procedure for the American Fisheries Society to follow.

BUSINESS MEETING AND REPORTS OF SESSIONAL COMMITTEES

The Business Meeting for hearing reports of Sessional Committees convened in the Royal York Hotel Tuesday, September 11 at 4:15 p. m. on Tuesday, September 11, 1956. President George E. Sprecher of Wisconsin presided.

President Sprecher called on Mr. William Voigt for the report of the Time and Place Committee. He next called for the Report of the Auditing Committee which was presented by Dr. Edward Schneberger, Chairman of the Committee. It was moved by Dr. John B. Moyle of Minnesota that the report of the auditing committee be accepted. The question was asked by Mr. Seth Gordon of California as to whether or not the recommendations in the Report of the Auditing Committee become the guiding policy for the incoming administration. President Sprecher replied that it was his understanding that acceptance implied the appointment of an *ad hoc* committee to study the three proposals presented by the Report and report their recommendations at the next Annual Meeting. Mr. Gordon recommended that the motion be amended to allow the incoming administration to expend at least a thousand dollars to employ editorial assistance immediately—not a year from now. He commented "We have eighteen hundred members and surely we are no longer so poor that we can't afford to compensate somebody on a part-time basis to do some of this work, and not impose on members of the Editorial Committee as we have been doing." He moved to amend the motion to authorize the incoming administration to expend up to one thousand dollars for part time editorial assistance immediately, and that this should be in addition to establishment of an *ad hoc* committee. The motion for the amendment was seconded by Dr. Karl F. Lagler of Michigan, and opened for discussion by the President. Mr. James H. Cornell of North Carolina asked for an opinion of the Auditing Committee as to the source of the thousand dollars. Mr. Gordon remarked "It can be taken from the permanent fund, if necessary." President Sprecher commented it would appear it would have to come from the permanent fund because the general fund might be depleted if we issue more than one volume of the TRANSACTIONS in the current year. President Sprecher commeneted that the Executive Committee had considered this subject at some length and it was the opinion of most of the members that a thousand dollars was far too small a sum to attempt to get this editing job done and that he understand Mr. Gordon's motion to be merely an attempt to subsidize in a small way the job of editing the TRANSACTIONS. Mr. Cornell seconded the motion for the amendment. The motion was put to a vote and carried unanimously. The original motion for approval of the report of the Auditing Committee was then put to a vote and the motion was carried.

Dr. Edward Schneberger of Wisconsin called attention to the Surety Bond for the Secretary-Treasurer of $7,500, and that because of the growth of the Society the Auditing Committee recommended that this Bond be increased to $25,000. He pointed out that this change required amendment of the Bylaws. It was moved by Dr. Schneberger that Section 3 of the Bylaws be changed to increase the amount of Surety Bond for the Secretary-Treasurer from $7,500 to $25,000. The motion was seconded by Dr. Karl F. Lagler. Mr. Gordon inquired as to the difference in premium for the bond. Secretary Speaker informed the Society it would result in

an increase from $17.50 to $62.55. The motion was put to a vote and carried unamimously.

President Sprecher then called on Dr. A. S. Hazzard of Pennsylvania for the report of the Resolutions Committee. He first presented Resolution No. 1 of the report of the Resolutions Committee. This resolution to raise the annual dues of the Society was seconded by Dr. C. Cottam of Texas and Dr. Paul R. Needham of California. An amendment was offered by Dr. H. S. Swingle of Alabama to raise fee for Sustaining Members from $10 to $25. It was seconded by Mr. Fukano of Michigan. It was pointed out by Secretary Speaker that there are now 32 Sustaining members. After some discussion the amendment was put to a vote and lost. President Sprecher then put the original motion to a vote and it was carried unanimously. Resolution No. 2 was then presented, seconded by Mr. Croker, put to a vote and carried. Resolution No. 3 was presented, seconded by Mr. Roach of Ohio, put to a vote, carried. Resolution No. 4 was then presented and seconded by Mr. William Voigt of Pennsylvania. Dr. Croker of California moved that under Item 1 of the Section on "minimum protective language" that the letter "A" be inserted before the word "primary" so that the phrase read "a primary beneficial use." The amendment was put to a vote and carried. The original motion was then put to a vote and carried. Resolution No. 5 expressing thanks to Editor Fukano was carried with prolonged applause, as was Resolution No. 6 expressing appreciation for Canadian assistance and hospitality at the meeting. President Sprecher then called on Dr. A. L. Pritchard of Ontario for the report of the Nominations Committee.

COMMITTEE ON TIME AND PLACE

WILLIAM VOIGHT

The Time and Place Committee met in joint session with the corresponding committee of the International Association of Game, Fish and Conservation Commissioners. It was recommended that the invitation of the State of Nevada be accepted. Later at a meeting of Executive Committees of both Societies it was agreed that the 1957 meeting of the American Fisheries Society shall be held at Las Vegas, Nevada, September 11-13 and the meeting of the International Game, Fish and Conservation Commissioners, September 9-11.

AUDITING COMMITTEE

EDWARD SCHNEBERGER

The report of an Auditing Committee is frequently considered to be a necessary routine that is perhaps boring to some. However, since we are dealing with the finances of the Society, the matter should receive the most serious attention of all members.

The duties of the Auditing Committee as stated in Section 18 of the By-laws are two-fold: The first is examination of the accounts of the Treasurer, and the second is consideration of the annual budget prepared by the Secretary-Treasurer and making of recommendation to the Society for action on it.

As for the first part of this assignment, the general fund accounts have

been examined in detail and all expenditures for the 1955-1956 fiscal year check out with the authorized vouchers and the Secretary-Treasurer's Report regarding the general fund is found to be correct. In reference to the permanent fund, it would be impractical and somewhat hazardous for the Secretary-Treasurer to bring the bonds and securities to the annual meeting. However, I am pleased to report that at the invitation of the Secretary-Treasurer, I had the opportunity, on March 26, 1956, to examine these documents held in Safety Deposit Box No. 1923 of the Iowa State Bank, Des Moines, Iowa. A formal report of this inspection was made to the President by letter on April 5, 1956. For the information of the Society, these securities consisted of the following:

15 U. S. Government Savings Bonds	$10,693.50
30 Shares Consumer's Power Co. @ 43⅜	1,421.25
6 Shares Central Illinois Light Co. @ 52½	315.00

The government savings bonds have a maturity value of $14,000.00. The desire of the Secretary-Treasurer to have members of the Society witness these securities speaks highly of his honesty and integrity. In addition, he is to be commended for his diligent efforts to keep accurate accounts for the Society.

As for the proposed annual budget for the 1956-1957 fiscal year, the Committee believes that adequate allocation of funds has been made to cover the anticipated expenditures. However, if by fortunate circumstances Volume 86 of the TRANSACTIONS should be available for printing prior to June 30, 1957, a deficit might occur. Therefore, it is recommended that the Secretary-Treasurer be authorized, subject to prior approval of the President, to transfer a sum sufficient from the permanent fund to the general fund to cover the deficit.

The Auditing Committee desires to make three recommendations at this time. These are as follows:

1. That a study be made of the size of the reserve fund that the Society should maintain. Presently this reserve fund is in excess of $12,000 of which the U. S. Government Savings Bonds have a maturity value of $14,000. It is believed that perhaps part of these reserve funds might be used to a good advantage to the Society and the Society be of greater service and value to its members.

2. Employment of secretarial assistant for the Secretary-Treasurer.

At the present time the Secretary-Treasurer carries a heavy workload of correspondence and bookkeeping on behalf of the Society and naturally he needs considerable secretarial assistance. The Society has been extremely fortunate in that the employing department of the Secretary-Treasurer has been very cooperative and has donated these services in cooperation with the Society. Such cooperation is indeed greatly appreciated by the Society; however, it does not seem reasonable that the Society should continue to expect such contributions. It is therefore deemed advisable that the Society look forward and make the necessary provisions to pay for such services out of

Society funds.

3. Employment of an Editor.

Presently there is a considerable lag between the time of the annual meeting and the issuance of the Transactions. It is appreciated that the editorial board has a most difficult assignment and criticism of the editorial board or any members is not intended. However, it is suggested that some of the delay might be avoided if the Society hired an editor and paid for his services. At least this means would provide some control over the editor and would enable the Society to be of more value and help to its members.

Consequently, it is the recommendation of the Auditing Committee that the President-elect appoint a special *Ad Hoc* Committee to study the three suggestions and report the results of such study with recommendations to the Society at the next annual meeting.

RESOLUTIONS COMMITTEE

ALBERT S. HAZZARD

1. Increase in Membership Dues

WHEREAS, The costs of operating the American Fisheries Society and of printing its TRANSACTIONS have increased substantially since the last revision of rates of dues at our Seventy-eighth Annual Meeting in 1948, and

WHEREAS, An increase of our present income is desirable if we are to avoid retrenchments and economies that detract from the value of services to members, now therefore

BE IT RESOLVED, That Section 8 of our By-laws, entitled Dues to Members, be amended to establish the following increases in rate of dues:

Active members: from $4.50 to $5.00 per annum

Library members: from $4.00 to $5.00 per annum

2. Encouragement of Basic Research

WHEREAS, There exists at the present time in the United States a widespread need for additional fundamental knowledge pertaining to fisheries investigational and management methods and practices, and

WHEREAS, The basic research required to accumulate and evaluate all of the needed facts in such fields as the chemical treatment of waters for the purposes of fish population manipulation and the improvement of game-fish brood-stocks is generally beyond the scope of the facilities available to the individual states, and

WHEREAS, This fundamental knowledge, once acquired, would be of inestimable benefit not only to the individual states, but also to the United States as a whole and to fisheries in general,

Now Therefore Be It Resolved, That the American Fisheries Society requests and encourages the United States Fish and Wildlife Service to continue and when necessary expand its basic research programs in the fields of common concern and interest to the various states.

3. Fishing Use of Water Storage Reservoirs

Whereas, A combination of shrinking stream fishing areas and record increases in angling pressure everywhere in the country has made it necessary that new water areas be opened to relieve the present situation, and

Whereas, There are many federal, state and city holding reservoirs above filtration and treatment plants that are now closed to angling, and

Whereas, No public health problems are involved because the water delivered from these holding reservoirs is both filtered and treated prior to domestic and industrial usage, and

Whereas, Most reservoirs now closed to fishing are accessible to large urban centers of population and could furnish a great expansion of angling areas, and

Whereas, Many municipalities such as San Diego, New York, Boston, and Los Angeles have found it profitable and safe to permit public fishing in such waters, under properly controlled conditions,

Now Therefore Be It Resolved, That the American Fisheries Society, at its annual convention held in Toronto, Ontario, on September 10, 11 and 12, 1956, urge all agencies concerned with, or responsible for, the administration of impounded waters to be used for domestic consumption to develop suitable plans for the implementation of angling in such waters,

And Be It Further Resolved, That a copy of this resolution be sent to the heads of the federal health departments in Canada and the United States and to Departments of Health in the various provinces and states and to the Fish and Wildlife Service of the United States and to the Wildlife Service of Canada. And further, that the health and conservation departments in each political subdivision be urged to resolve the problems of using domestic water supply reservoirs for public recreation.

4. Safe-guarding Recreational Use of Waters

Whereas, The doctrine of water appropriation, long extant in the westerly states, is rapidly moving eastward into the more humid parts of the country, and

Whereas, This trend is being accelerated and complicated by the rapid growth in population and industrialization, as well as more intensive cultivation of the land for agricultural production, and

Whereas, Pressures are increasing for the additional diversion of water from surface sources for municipal, industrial and agricultural use, and

Whereas, The demand for recreational opportunity utilizing water is

likewise growing swiftly, and has valid reason for consideration,

THEREFORE BE IT RESOLVED, That the American Fisheries Society, in convention assembled, does strongly urge upon both administrators and technicians of all the states and provinces, the following fundamental principles:

1. Waters of a stream should not be diverted to such an extent as to endanger the survival of an adequate population of desirable aquatic life in the natural channel.
2. Similarly, waters of a natural lake should not be diverted to an endangering extent.
3. Relatively clean upstream waters of a stream should not be diverted to an extent or degree that would endanger essential values downstream.

BE IT FURTHER RESOLVED, That the Society does recommend the following minimum protective language in any new state laws intended to control or bring about the appropriation or allocation for public or private use of flowing waters:

1. The nonconsumptive recreational use of water shall be considered under law to be a primary beneficial use.
2. Allocations of water should be based upon accurate and up-to-date inventories of water quantities and flow.
3. Allocations of water should be based upon minimum flows rather than maximum or so-called average flows.
4. Provisions outlined in three previously numbered paragraphs relative to diversions from streams and lakes and to the protection of essential values, should be specifically written into any state law, or amendment thereto, enacted for the appropriation or allocation of water.

AND BE IT FURTHER RESOLVED, That copies of this resolution be sent to the Prime Minister of Canada and to the premier of each province and to the governor of each state and to the heads of the Conservation agencies of each state and province.

5. *Thanks to the Editor*

WHEREAS, Kiyoshi G. Fukano has well and faithfully served as a member of the Editorial Board and as Editor-in-Chief for the past four years,

AND WHEREAS, This work has been done on his own time and at considerable personal sacrifice,

AND WHEREAS, He no longer can devote the time and energy to these duties—nor should he be asked to do so longer,

NOW THEREFORE BE IT RESOLVED, That the American Fisheries Society in convention assembled does hereby express our deep appreciation for this service to the organization.

6. Thanks for Assistance and Hospitality

WHEREAS, The American Fisheries Society has again been the guest of the Province of Ontario, Canada, and has again enjoyed the warm and friendly hospitality of the City of Toronto,

NOW THEREFORE BE IT RESOLVED, That our appreciation be extended to the Ontario Department of Lands and Forests, and to the Toronto Angler's and Hunter's Association, to the Canadian National Sportsmen's Show and to the management of the Royal York Hotel for the entertainment and many courtesies extended during the 86th Annual Meeting of the American Fisheries Society.

NOMINATING COMMITTEE

A. L. PRITCHARD

There has been some dissatisfaction expressed in recent years by the members of the Society with the nominating procedure whereby only a single candidate was proposed by the Nominating Committee for each office, especially for the position of Second Vice President. To allay any fears that the democratic principles of the Society are being violated, your Committee places in nomination two names for the position of Second Vice President.

It should be pointed out that by submitting two names we are merely making a vote necessary and that this does not deny anybody the opportunity of submitting another name from the floor of the convention.

The matter of succession to the position of President relative to area representation has also been considered. It was recognized by all that in the early days when the Society was small and when membership was limited, the policy, and it was a policy and not a rule, of having the Second Vice President come one year from the U. S. Federal Service, one year from State Service, and perhaps once in every three or four years from Canada, was quite justifiable in view of the distribution of the membership.

This policy has been adhered to recently and it is our feeling, after considering the distribution of the membership, that it should not be adhered to. Approximately, the membership is 1500 from the States and their organizations, 150 from the Federal Service of the United States and 100 from Canada. We, therefore, decided that the nominee for Second Vice President should again this year be from a State organization. The question of geographical location was also considered in nominating

a Second Vice President, and it is the opinion of the Nominating Committee that he should come from the northeastern part of the area which we represent.

Mr. President, I will now read the nominations suggested by your Nominating Committee:

Officers

President ..... C. F. Pautzke, Washington
First Vice President ..... H. S. Swingle, Alabama
Second Vice President ..... Lee S. Roach, Ohio
W. Mason Lawrence, New York
Secretary-Treasurer ..... E. B. Speaker, Iowa
Librarian ..... Howard A. Tanner, Colorado.

Committee on International Relations

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PRESIDENT SPRECHER: Are there any other nominations for members of the Standing Committees? If it is the pleasure of the Society, we will vote on the recommendations of the Nominating Committee for Standing Committees in one motion. All in favor of the nominations presented for members of the Standing Committees signify by saying "Aye"? Opposed, "No"?

The Standing Committees as proposed by the Nominating Committee, are elected unanimously.

Are there any other nominations for officers of the Society? We have two nominations for Second Vice President and one nomination for all the other officers.

If it is agreeable to the Society we will vote for the four officers for which the Nominating Committee has provided only one nominee—namely President, First Vice President, Secretary-Treasurer and Librarian.

Are there any other nominations for these officers? The question then is, all in favor of electing the candidates nominated for the offices except that of Second Vice President, signify by saying "Aye"- Contrary, "No"?

The motion is carried unanimously. These officers are therefore elected.

PRESIDENT SPRECHER: Now we will ask for additional nominations for Second Vice President. We have two names; Lee S. Roach of Ohio and W. Mason Lawrence of New York. If there are no other names I will close the nominations.

Will the the Secretary please distribute the ballots? I will appoint as tellers Fred Thompson, Seth Gordon and Al Hazzard. Will they come forward and count the ballots? (Ballots distributed and tellers come forward to table).

PRESIDENT SPRECHER: Please count the ballots in plain view of all the voters. The polling is now closed and election will be by a simple majority. Many of you will remember a two-thirds majority was once required. But that has been changed. Election is now by a simple majority.

MR. GORDON: Here is a "Joe Smith." [Laughter]

PRESIDENT SPRECHER: Will Joe Smith please stand up? Members of the Society, I will give you the result of the voting: W. Mason Lawrence, 62 votes, Lee Roach,

32 votes and Joe Smith 1 vote. W. Mason Lawrence stands elected as Second Vice President. [Applause]

MR. ROACH: Mr. President; May I, if it is in order, ask that the Society cast a unanimous ballot for my good friend, Mr. Lawrence.

PRESIDENT SPECHER: You would be very much in order. Is there a second to Mr. Lee's motion.

MR. WILLIAM VOIGHT: I will second that.

PRESIDENT SPRECHER: All in favor of casting a unanimous ballot for W. Mason Lawrence signify by saying "Aye"?

Mr. Lawrence is unanimously elected Second Vice President of the American Fisheries Society.

Now in these concluding seconds, I have just one more job to perform; it is to see that our new President is properly installed. During the last eight years that I have been an Officer in this organization, I am very proud to say that I have never worked with more cooperative people and I know that those with whom I have worked are the greatest fisheries people in the world.

The man who is about to step into my shoes is far more able to fill them than I have been during the last year. Because of his physical stature I have some trepidation about whom I should appoint to bring him up to the platform I have finally decided that the two men in the audience most capable of doing this are Ralph Hile and Lee Roach.

[President-elect Pautzke was escorted to the platform by Dr. Ralph Hile and Mr. Lee Roach amid applause from the audience]

CONCLUDING BUSINESS

PRESIDENT PAUTZKE: I realize I am stepping in the foot tracks of a long lineage of illustrious presidents and know the responsibility I am accepting here. Believe me, I plan to make great efforts to stimulate the interests of all of us in the welfare of the Society. I will need the assistance of all of you—but I don't believe there will be any disturbance that I cannot physically control.

Would the First Vice President and Second Vice President please come forward? [Dr. Swingle and Mr. Lawrence come to the platform]

PRESIDENT PAUTZKE: Is there any new business to come before the meeting?

SECRETARY SPEAKER: Mr. President, there are two very important items of business to come before the meeting of the Society at this time. First is the presentation of the names of proposed new members to the Society at this time. sentation of the names of proposed new members to the Society. With your permission I will present them.

PRESIDENT PAUTZKE: Approved.

[Secretary Speaker presents names of proposed new members. The proposed new members are accepted into the Society by unanimous vote]

SECRETARY SPEAKER: Mr. President, with your permission, I would like to offer one more very important item of business. It gives me considerable pleasure to announce that the members of the Society in the North Central Region would like to petition the Society for formal permission to organize a North Central Division. Dr. Raymond E. Johnson of Minnesota will make the presentation.

DR. RAYMOND E. JOHNSON: I should like to read two paragraphs from a letter sent by Dr. Gerking to Secretary Everett Speaker, explaining the position of the proposed North Central Division:

"On behalf of the members of the American Fisheries Society in North Central United States and Canada, I am presenting the credentials required to petition for the formation of a North Central Division of the American Fisheries Society.

"The credentials include this letter of transmittal, a copy of the Minutes of the organizational meeting, a petition signed by thirty-nine members in good standing

of the American Fisheries Society, and a copy of the By-Laws of the proposed Division.

"We hope that our petition will receive favorable consideration from the Executive Committee, thereby augmenting the strength of the national Society and consolidating the membership of our Region."

The petition is brief. It reads:

"The undersigned members in good standing of the American Fisheries Society, resident in the North Central part of the United States and Canada, really not represented by any Division of the Society, do hereby petition for the establishment of a North Central Division of the American Fisheries Society.

"This request is initiated in accordance with the provisions of Article 6 of the Constitution, at the organizational meeting of the proposed North Central Division, held at Purdue University, Lafayette, Indiana, December 13, 1955."

Now Mr. President, in order to facilitate action and discussion on this petition, I move that the petition for the formation of a North Central Division of the American Fisheries Society be accepted.

DR. SHELBY GERKING: I will second that motion.

PRESIDENT PAUTZKE: It has been moved and seconded that the petition for approval by the parent society of a North Central Division be accepted. Do I hear any discussion or questions?

DR. PAUL R. NEEDHAM: Mr. President; May we have a description of the boundaries of the area covered.

DR. JOHNSON: Briefly, the area includes everything not now included by other Regional Divisions. It includes the States of Michigan, Ohio, Indiana, Wisconsin, Illinois, Iowa, Minnesota, North and South Dakota, Nebraska, Kansas, and the Province of Manitoba.

PRESIDENT PAUTZKE: Is there any further discussion? Are you ready for the question? All those in favor of this new North Central Division of the American Fisheries Society say "Aye"? Opposed "No"? It is unanimously carried that a North Central Division be established.

There is one more item. Both as President of the Society, and for myself, I wish to extend our retiring President, Mr. Sprecher, our gratitude for the constant attention and leadership he has given the Society during the past year. [Prolonged applause]

Gentlemen, is there any further business to come before the meeting? If not, I will entertain a motion that this meeting be adjournd.

DR. PRITCHARD: I move that we adjourn.

MR. FRED THOMPSON: I second the motion.

PRESIDENT PAUTZKE: It has been moved and seconded that we adjourn. All those in favor say "Aye". Carried. [The Eighty-Sixth Annual Meeting of the American Fisheries Society at Toronto adjourned at 4:30 p. m. on September 12, 1956]

Appendices

INSTRUCTIONS FOR PREPARING MANUSCRIPTS FOR THE TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY

(REVISED 1954)

Please check each item below before the final typing of your manuscript and help reduce the costs of publication, save your Editorial Board much needless work, and avoid delay in the publication of the *Transactions*.

The following instructions were not drawn up arbitrarily but were condensed from regulations contained in the best style manuals. Certain instructions may appear unnecessary, but they are nevertheless essential for the proper handling of materials by the printer and the editor.

I. MECHANICAL DETAILS

1. **Manuscripts must be typewritten double-spaced,** including titles, headings, legends for tables and illustrations, and literature citations. Write manuscript only in simple upper and lower case. *Do not use all capital letters for any purpose and underscore only where italics are intended.*

2. **Carbon copies or originals made with a worn-out ribbon will not be accepted.** Do not use thin paper; heavy bond is preferred.

3. **Margins** at top, bottom, and both sides must be no less than 1¼ inches to allow space for the insertion of directions to the printer and necessary corrections.

4. **Pages must be numbered in consecutive order,** including tables and pages carrying legends to figures. Tables and legends of figures must be inserted near their place of reference in the text. Place your name on the upper left-hand corner of each sheet of manuscript and write your name in pencil on the back of all photographs and drawings.

5. **Illustrations.** Make a separate page of each figure legend and limit the number of figures to those absolutely necessary to clarify or supplement text. Only sharp, glossy photographs can be used. Photostats will not be accepted. All drawings, charts, and diagrams should be prepared in waterproof India ink on high-quality paper or tracing cloth. Graph paper must not be used. No erasures should be made. Shading should be limited to a minimum and when used the lines should be kept open. The curves of graphs should be drawn much bolder than any guide lines or ruling. Lettering should be bold and sufficiently large and spaced apart so that the letters or numbers will not be less than 1 millimeter high or come in contact when reduced. Drawings should be made at least twice the size required for reproduction, and when large should be of proper proportion so that they will not exceed 4¼ by 6½ inches (inclusive of legends) when reduced. *All explanatory matter other than the units along each axis of a graph or diagram and those designations needed for clarity should be placed in the legend.* The legend, which should be typewritten on a separate sheet, will be set in type below the figure.

Make proper reference in text to all plates, maps, and charts, and designate all of these, except tables, as figures, numbering them in consecutive order with Arabic, not Roman, numerals.

6. **Footnotes** in text should be numbered consecutively and should be placed immediately after the full line of text in which the reference mark occurs, but do not break a line of text to insert footnote. Separate the footnote from the text by two horizontal lines, one above and one below the note. In each new table footnotes should begin with 1. Do not use asterisks or other symbols to call attention to footnotes to tables.

7. **The title** of the manuscript, together with the author's name, division, or depart-

ment, and post office address, should always appear at the top of the first page of the manuscript as follows, allowing at least *triple space between lines* to permit the insertion of instructions to the printer.

TREATMENT OF DISEASES OF BROOK TROUT

JOHN EDWARD DOE

Department of Conservation, Lansing, Michigan

8. **Underscore** (italics) all scientific names of genera and species, both animals and plants, in both text and tables. Do not underscore or use all capital letters for scientific names of a category higher than the genus: Esocidae; *Esox lucius. Do not underscore any words unless italics are intended.*

9. **Inspect papers** in the last volume of the *Transactions* if you have questions concerning the arrangement of materials.

II. STYLE

10. **Bibliographic references** in text should give name of author and year of publication in one of the two following forms. "A similar reaction to light was reported by Doe (1932)." "This type of reaction appears to be common (Doe, 1932)." Do not use letters or numbers or footnotes for references. If more than one publication by the same author is given for a year, use the alphabet to designate the correct paper, thus: (Doe, 1932a) or (Doe, 1932b). In the bibliography do not repeat the author's name if reference is made to more than one of his publications, but list his publications in chronological order beginning with the earliest one. In citing a joint publication invert the name of the senior author but not of the co-author or co-authors. *Do not include any reference not mentioned in the text.* List authors in alphabetical sequence. Capitalize the first word and proper names only in the title. Follow the arrangement given below, to be placed at end of paper:

LITERATURE CITED

DOE, JOHN C., J. W. BROWN, and H. W. GREEN
1939. Treatment of diseases of brook trout. Trans. Am. Fish. Soc., Vol. 68 (1938), pp. 450-461.

List only bona fide publications under Literature Cited. Do not list personal communications, typewritten reports, or processed materials given only limited distribution but rather give the appropriate citations in text footnotes at point of reference.

Please check your references carefully as to titles, spelling, capitalization, italics, diacritical marks, abbreviations, etc., agains thteir original sources, after the final typing and *state beneath your bibliography that you have done so.* Many bibliographic titles published in the *Transactions* have been found to be incomplete and inaccurate. Help us correct this situation.

11. **Tables.** Every table except leader work must have a heading and must be typewritten on a separate page. In preparing tables please make certain that they are not too large to appear on a single printed page and that the arrangement conforms with the format of the *Transactions. Improperly prepared tables lead to the return of many manuscripts.* Number tables consecutively with Arabic numerals (1, 2, 3, etc.). Spell all words in tables, including such words as "millimeters," "ounces," and "average" (except months *with date,* in body of table), and capitalize, as a rule, the first word only in headings in the first column or over other columns. Precede all decimal numbers with zero. Use dollar sign only with first number at top of column and under each cross rule.

12. **Capitals.** Capitalize words when used as a part of a proper name or of an identifying number or letter, or when referring to particular States, Governments, and organized bodies, or when used as proper names. For example: Lake Michigan, State of Michigan, the State, the Province, the Republic, Washtenaw County, Ann Arbor Township, Huron River, Pacific Ocean, North Atlantic, Northern States, Hoover Dam, Pond A, State Fish Farm No. 1, Pisgah National Forest, American Fisheries Society.

Capitalize names of sections of the United States, or of any other country, as Middle West, but use lower case for a term prefixed to any such sections, as eastern North Atlantic States.

Capitalize any term (except page or pages and age group) preceding Roman numerals, as Article I, Chapter II, Sample VI, etc. Also capitalize such terms as Appendix 1 or Appendix A, Experiment 2, Table 4, and Figure 6.

Use lower case for scientific and common names of species. Capitalize scientific names of higher categories.

13. **Abbreviations.**

(a) Abbreviate the following:
Clock time, if connected with figures—2:30 a.m.
Temperatures, F. (Fahrenheit).
Degrees, whether referring to temperatures, longtitude and latitude, or angles, etc.—75°, 75° F., 75° C.
Number, if preceding figures—No. 125; otherwise spell out.
United States, if preceding name of a department or a bureau of a vessel, etc.—U. S. Department of the Interior, U. S. S. *Indiana.*
Months, in body of tables and footnotes to same when followed by day of month—Apr. 5 - Sept. 2 (but April - September).

(b) Do not abbreviate the following:
States, cities, etc.
Months, in text or in headings of tables—April 5 - September 2.
Measures and weight, except p.p.m., 6 inches, 20 millimeters, 5 ounces, 1.5 acres, etc.
Percentage, 12 percent, a percentage of 25.5

14. **Numerals.** Spell out *isolated* numbers less than 10, but treat alike all numbers in a series of connected groups. For example: The nets contained nine bluegills. The catch included 9 bluegills, 20 smallmouth bass, and 123 pumpkinseeds.

Use figures for enumerations of quantities and measurements, such as dimension, weight, area, volume, distance, clock time, time, money, percentage, degrees, proportion or ratios, ages, dates, page numbers, decimals, and mixed numbers (spell out common fractions if alone but use numeral if part of a hyphenated expression: one-half inch; ½-inch mesh). Examples: $3.00 per 20 pounds; 5 feet 6 inches; 10 miles; 6 acres; 15 cubic centimeters; 4:30 p.m.; fish died in 1 hour and 20 minutes; 25.5 percent; 75° F.; 1:10,000; fish 2 years 6 months old; 2-year-old fish; June 29, 1936; January 1938; the 20th day of March; 1937-1938; 4.5 p.p.m.; 0.25; 1½ pages; page 215.

Write 8 by 12, not 8 x 12 unless multiplication is indicated. Write 50-50, not "fifty-fifty."

Do not use two figures when two numbers appear together, unless the first enumeration exceeds 100: ten 12-room houses; twenty 6-inch bluegills; 120 6-inch bluegills.

Spell out figures beginning a sentence, but avoid such use of numerals if possible. Spell out both numbers of two related amounts at the beginning of a sentence in such expressions as "Twenty to twenty-five lake trout," but write "Two hundred fifty rock bass and 325 lake trout were shipped."

In expressing large numbers the word *million* (or a similar larger group term) may be spelled out: 20 million, 2¾ billions.

15. **Use of hyphen.** Many compound words when used as nouns are not hyphenated but require the hyphen when used as adjectives. For example note the following sentences: "This species is adapted to *cold water.*" "Ciscoes are *cold-water* fish." Write "fish culture," but "fish-culturist." Check your manuscript carefully for use of hyphen. The words, "subspecies," "upstream" and many other words originally of compound derivation are written without a hyphen.

III. SUBJECT MATTER

16. **Condense your paper** to the limit and omit all needless verbiage. The manuscript should be simple, clear, concise, accurate, consistent, and complete. *Accuracy* in subject matter, in scientific names, and in bibliography is especially important. **Papers which are too poorly written will be rejected.**

17. **Be definite in reference to species.** The full common name and the scientific name must be given for each species mentioned. Scientific names may be omitted from the title, if desirable, but must be given at first reference to the species in the text. Once given, scientific names need not be repeated. Follow the Society's official list of names. Do not write "smallmouth," "brook," "rainbow," etc., when you mean "smallmouth bass," "brook trout," "rainbow trout," etc.

18. **Things to avoid.** Words that do not appear in the dictionary in the sense employed should be avoided. The words "case," "instance," "showed," "found," "gave," and presented, are greatly overworked in manuscripts.

Avoid the repeated use of *participles* which, as a rule, weaken sentences. In the following illustration note the improvement when the words in parentheses are used: "The principles underlying (that underlie) the production of beef are essentially the same as those involving (that are involved in) the production of bass."

Avoid *split infinitives.* Please check your manuscript for this common error.

Avoid the use of *this* and *these* as substantives. Compare, for example, the following two sentences for effectiveness: *"This* was true in every *case." "The mortality* was *high* in every *pond."*

Avoid the use of a long series of nouns and adjectives as modifiers.

Avoid the use of such meaningless section headings as "Data" and "Discussion."

19. **Things to remember.** Well written papers are the product of careful thought and hard work. Usually they require repeated revisions that incorporate suggestions from discerning and honestly critical associates. Please make these revisions *before* submitting your manuscript.

Good writing is to a large extent a matter of good taste and good manners. Careless presentation and poor organization are rank discourtesy toward the readers.

Careless writing may save time but, once printed, a weak paper stands long as a discredit to its author.

20. **Abstract of paper.** Give a brief abstract at the beginning of your paper. Do not include a "Summary" at the end of your paper; if "Conclusions" are given make them brief and not a duplication of materials in the abstract.

Prepared by the Editorial Board

AMERICAN FISHERIES SOCIETY

Membership List

Compiled, December, 1956

[*Indicates Honorary Members; CAPS Indicate Life Members]

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'56 Alderdice, Don F., c/o Pacific Biological Sta., Nanaimo, B. C., Can.
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'55 Atkinson, J. F., Dorion Trout Rearing Sta., Dorion, Ont., Canada
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'55 Bailey, Merryll M., Ohio Fisheries Bldg., Sandusky, Ohio
'37 BAILEY, REEVE M., Univ., of Mich., Ann Arbor, Mich.
'33 Bailliere, Lawrence, Ozark Fisheries, Stoutland, Mo.
'37 Baker, Clinton L., c/o Southwestern, Memphis, Tenn.
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'55 Baker, W. Donald, UK--30, Vetville, Raleigh, N. C.
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